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ABSTRACT

The symposium was organized in an attempt to focus attention on self-paced methods in chemistry at all levels of undergraduate instruction. In this volume, 21 papers are presented in which the major intent of each is to individualize instruction. Several of the entries appear under the heading of the Keller Plan, a self-pacing instructional approach in which materials are divided into small units. Other computer-based instructional programs for all levels of undergraduate study are presented. Included in the volume are 17 additional self-paced instructional programs. (Editor/CP)

Edited by
Bassam Z. Shakhashiri

PROCEEDINGS OF THE SYMPOSIUM ON

# SELF-PACED INSTRUCTION IN CHEMISTRY

165th National Meeting
American Chemical Society
Division of Chemical Education, Inc.
April 11, 1973
Dallas, Texas

# FOREWORD

The Symposium on Self-Paced Instruction in Chemistry was organized in an attempt to focus attention on an area of considerable interest to the chemical education community. The apparently successful results of "tinkering" with formats of instruction in other disciplines have influenced many college chemistry instructors to consider alternatives to the traditional format of teaching chemistry. The major thrust is to individualize instruction. Many instructors have taken bold steps in changing the teaching-learning environment and seem to be primarily concerned, for the moment anyway, with modifying schemes of instruction. Hopefully, the content of instructional programs will be the next area of concern.

The papers presented in this Symposium are representative of numerous efforts made at all undergraduate levels and in various branches of chemistry. They deal with small-size as well as with large-size classes and many include descriptions of laboratory programs.

I wish to acknowledge the cooperation and promptness of the speakers in providing copies of their papers. The support of the Division of Chemical Education in sponsoring the Symposium and publishing this booklet is gratefully acknowledged.

Bassam Z. Shakhashiri
Symposium Chairman
Department of Chemistry
University of Wisconsin-Madison

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# THE KELLER PLAN

## INTRODUCTORY REMARKS

Bassam Z. Shakhashiri

Students are learners and as such need a facilitator. They see much of what they "have to learn" as verbal and mathematical statements about chemical phenomena. Their confusion increases when seemingly disorganized facts and unrelated concepts are mentioned either in a text or in a lecture. They cry for guidance and direction. The instructor might guide a bewildered student if they meet in individual tutorial sessions. Such one-to-one tutorials seldom take place even at small institutions. Often, the student's scholarly interests are not pursued or allowed to develop because of overwhelming required assignments.

Keller Plan courses, in principle, offer each student the opportunity to learn prescribed material at his own pace. The prescribed material is divided into units; the student is to master each unit before proceeding to the next. Mastery is measured by means of a test that can be taken repeatedly until a certain prescribed level of performance is achieved. Achievement is rewarded by giving the student the study questions for the next unit. Periodically, upon the completion of a set of units the student is invited to attend a lecture designed to stimulate and encourage his interest in material based on what has been mastered. Course grades are determined by the number of units completed according to a set contract announced at the beginning of the course. Students who master the material faster than others are often asked to tutor the slower students in lieu of taking an examination. Fast achievers might be given special independent study projects to work on.

Many chemistry courses that have been offered in the Keller format are described in the following papers. Several conclusions and inferences are made. In many instances the "Hawthorne Effect" is observed. This should not detract from the benefits of the Keller Plan since one of the major aims is to cause favorable student response to a change in the teaching-learning environment. Each instructor should decide for himself whether or not the Keller Plan, in any form, is compatable with his approach and with the resources he has available. Further and wider adaptation of the Keller Plan in chemistry and in other courses is necessary to help remove doubts about the validity of this approach to learning.

A SELF-PACED INSTRUCTION CHEMISTRY COURSE AT ITHACA COLLEGE

by

Robert F. Pasternack*

Chemistry 111-112, Fundamentals of Chemistry, is offered as a terminal course for students not majoring in the sciences. The fall semester is devoted to principles and some inorganic chemistry and the spring semester covers organic and biochemistry. The course is required of Physical Therapy students who comprise about 75% of the total course enrollment of some hundred students. The Physical Therapy program is a highly competitive one and these students are quite grade conscious. They traditionally "put up" with the chemistry requirement although course evaluations in prior years would indicate that they generally do not find the course interesting nor enjoyable. The remaining 25% of the student population take Chemistry 111-112 as a free elective or because they are majoring in some other health related field such as the Administration of Health Services or Speech Pathology and Audiology for which a certain number of hours in some natural science is required.

I offered to teach Chemistry 111 for the fall semester of 1972. Some 107 students enrolled in the course and on the first day of class I distributed a description (see Appendix A), drawn largely from the writings of Keller and Green (1-4), on the Keller Plan experiment I planned to conduct at Ithaca College. The students were given an opportunity to read this material and then I discussed it with them, answered questions and called for volunteers. Fifty-six students volunteered and submitted their schedules. Twenty students were selected at random from the fifty-six volunteers and quiz sections were scheduled for late in the afternoons on Monday, Wednesday and Friday to minimize conflicts. The students participating in the Self-Paced Instruction section were barred from the lectures, and one of the tutors who attended the lectures never saw a SPI student there.

In a certain sense, the two sections (lecture and Keller) were kept distinct in my mind. If I decided to enrich the lecture material, I did not allow the fact that the Keller students were not exposed to this material to constrain me in any way. In short, I did the best job I could in each of the approaches without worrying about equal presentations or equal depth of discussion. For example, chemical bonding was discussed in greater detail in lecture but only the Keller Plan students were exposed to material on air and water pollution. However, on the final exams, I was careful not to include material which one group or the other had not seen (vide infra).

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In the first part of the semester I met weekly with the two tutors, a senior and a junior chem major, and the course manager, the Chemistry Department secretary. I impressed on the tutors the importance of engaging each of the students in conversation about the material regardless of whether the student had scored 100% (the only passing grade) on a quiz or not. The tutors followed this instruction and established excellent rapport with their students. Furthermore, they found no evidence of cribbing nor cheating of any sort. I suggested that the tutors spend no more than five minutes per student per quiz but this suggestion was largely ignored. The tutors were kept constantly busy answering questions and discussing the quizzes with the students with the duration of these discussions limited only by the pressure of waiting students. As it developed, these extended discussions quite likely had a profound influence on the results of this experiment as will be discussed later.

I spent the quiz periods (1 1/2 hours, three times a week) being available and chatting with students. I spent about half of my time in the quiz room and about half in the grading room and made it a point never to appear busy with my own work. Therefore, students could feel free to approach me with questions without feeling they were disturbing me. However, students tended to turn to one another for help or to the tutors before they would come to me. I interpret this as a positive feature of the Keller Plan since it indicates 1) students try to work out their own problems; and 2) they think of their tutors less as evaluators and more as preceptors who are helping them through the course.

Procrastination proved to be no problem in the Ithaca experiment (cf. Figure 1) although I found enrichment lectures as a spur to greater effort to be completely useless. I offered sessions on "Why We Grow Old," "Chemistry of the Mind: Schizophrenia," and "Recent Developments in Cancer Research," but these were not attended and so I discontinued the enrichment lectures. My experience leads me to conclude that procrastination is best alleviated by: 1) making the progress of each member of the Keller section a matter of public record, 2) basing midterm grades on the number of units passed, and 3) offering an early final to students completing all units by an agreed upon date. On October 18th, a memo on midterm grades was posted (see Appendix B). As may be seen from Figure 1 the class progress record shows a sudden increase in pace at just this time. The date agreed upon for the early final was November 17th. Once again, the class accelerated its progress shortly before this date. By the end of the semester, all Keller students but one (who withdrew unofficially from the course in October) had finished all of the units.

Throughout the semester, there was considerable student enthusiasm for self-paced instruction. Course evaluations were distributed and the following comments are fairly typical:

> "The greatest advantage is that you can work on the units in your spare time. I am glad that I didn't have to come to class every time because I needed that extra time for studying for other tests. Another advantage is that it is easier to get questions answered in the self-paced instruction than in the large group because the tutors and Professor Pasternack are willing to spend a longer amount of time answering your questions."

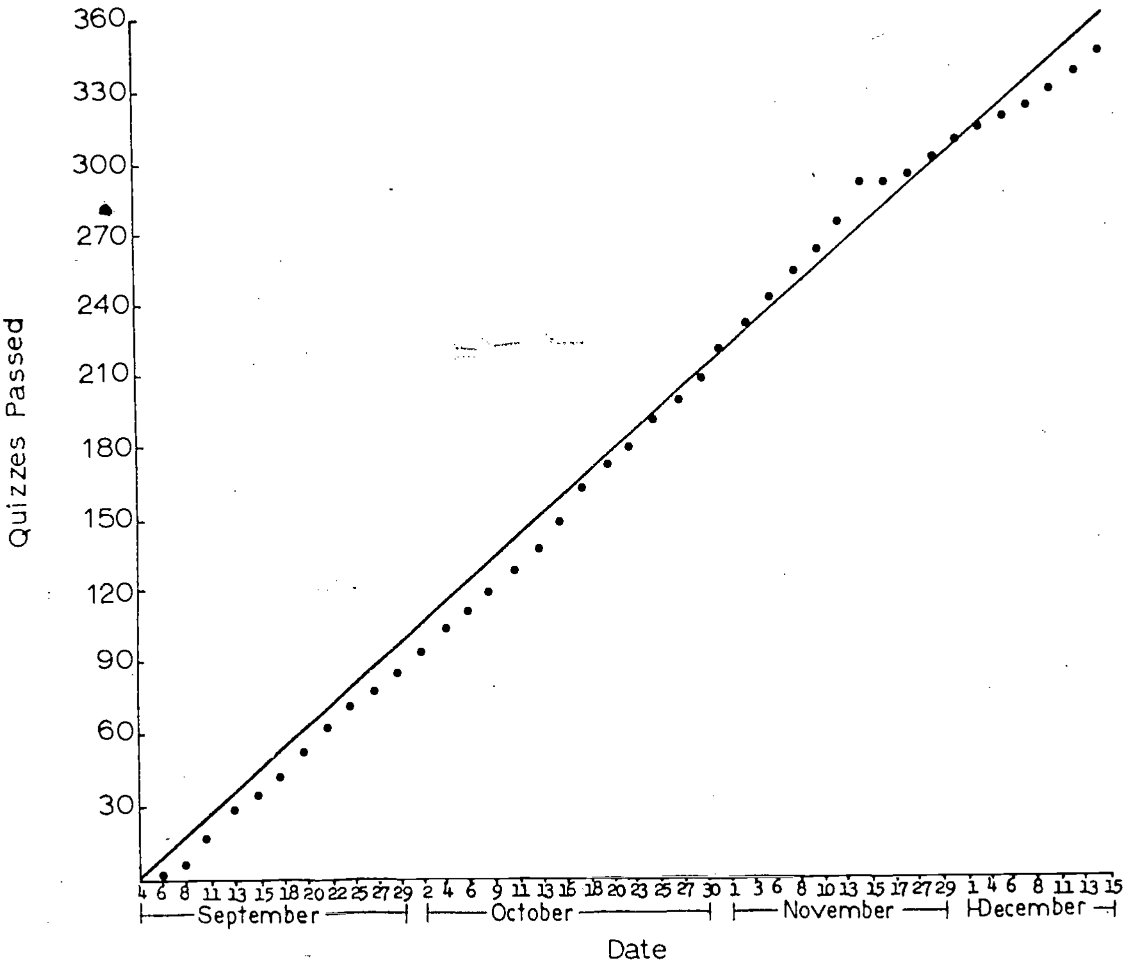


Figure 1: A record of class progress. The straight line represents the minimum constant rate for all students to complete all of the units. The filled circles show the progress of the class.

"By this approach, I found I was able to adjust the pace that I wanted to go at and was able to go at. Also I felt an accomplishment of being able to learn so much of the material on my own. Also if I needed help, I knew where and when I could get it."

"The frequent testing gives you an excellent feeling for your own strong and weak points and does not allow a gross deficiency to go unchecked. It also forces you into a realistic appraisal of your own progress."

The students were asked to comment on the disadvantages to this approach. Most students saw no disadvantages but a couple of comments are worth noting:

> "Unfortunately the program is not compatible with many students. Some students would be unable to learn on their own. They have always had someone tell them exactly what the information to be gained is. Lack of self-motivation."

> "Some people need classroom work to make them keep up and otherwise will get behind. In a course like this those kind of people are in bad shape."

> "If you were having difficulties with a certain unit it was difficult to catch up and as a result, you lost time and received an NFT [Ed. Note: NFT stands for Not For Transcript, i.e., a failure] as your midterm grade. I think it was unfair because you are still working and learning at your own pace. How can you fail someone for working at their own pace. I am learning yet receive a failing grade for being a little slower than usual. I never had a good chemistry course before and find it difficult to learn something in 2 days. Chemistry is not my only course!!"

The students were asked if this approach put an excessive burden on them. Almost all of the students felt that they had to work harder at this course than others but did not feel it constituted an unfair burden. One comment was: "Although I did work harder at times in this course than my others, I never felt burdened because I got a lot out of the time I put in." Students were also asked to propose changes for future self-paced instruction courses. Most thought the approach was satisfactory as it stands but several suggested a shorter wait between failed quizzes (30 minutes, see Appendix A) and two or three suggested supplementary material such as films.

Ten of the Keller Plan students finished all the units by November 17th and thus qualified for an early final exam. I prepared two finals which I attempted to make of comparable difficulty, Final I and Final II. Final I was administered to the ten accelerated Keller Plan students on December 6th. The remaining students, both lecture and Keller, took the regularly scheduled final on December 18th. All but fifteen randomly selected lecture students took Final II; the randomly selected students did Final I. By comparing the performance of the lecture students only, I determined that Final I was slightly more difficult than Final II and made an appropriate adjustment. The results as shown in Figure 2 were as follows: for the seventy-four students taking the final exam who did not participate in the Keller Plan, the average on the final examination was 75.2; for the nineteen Keller students who took the final, the average was 66.9. Considering the lecture students only, forty-three did not volunteer for the Keller Plan, their average was 76.5; thirty-one did volunteer and their average was 73.3. It should be noted, however, that 14% of the non-volunteers and 14% of the volunteers dropped the course while only one Keller student out of twenty or 5% dropped.

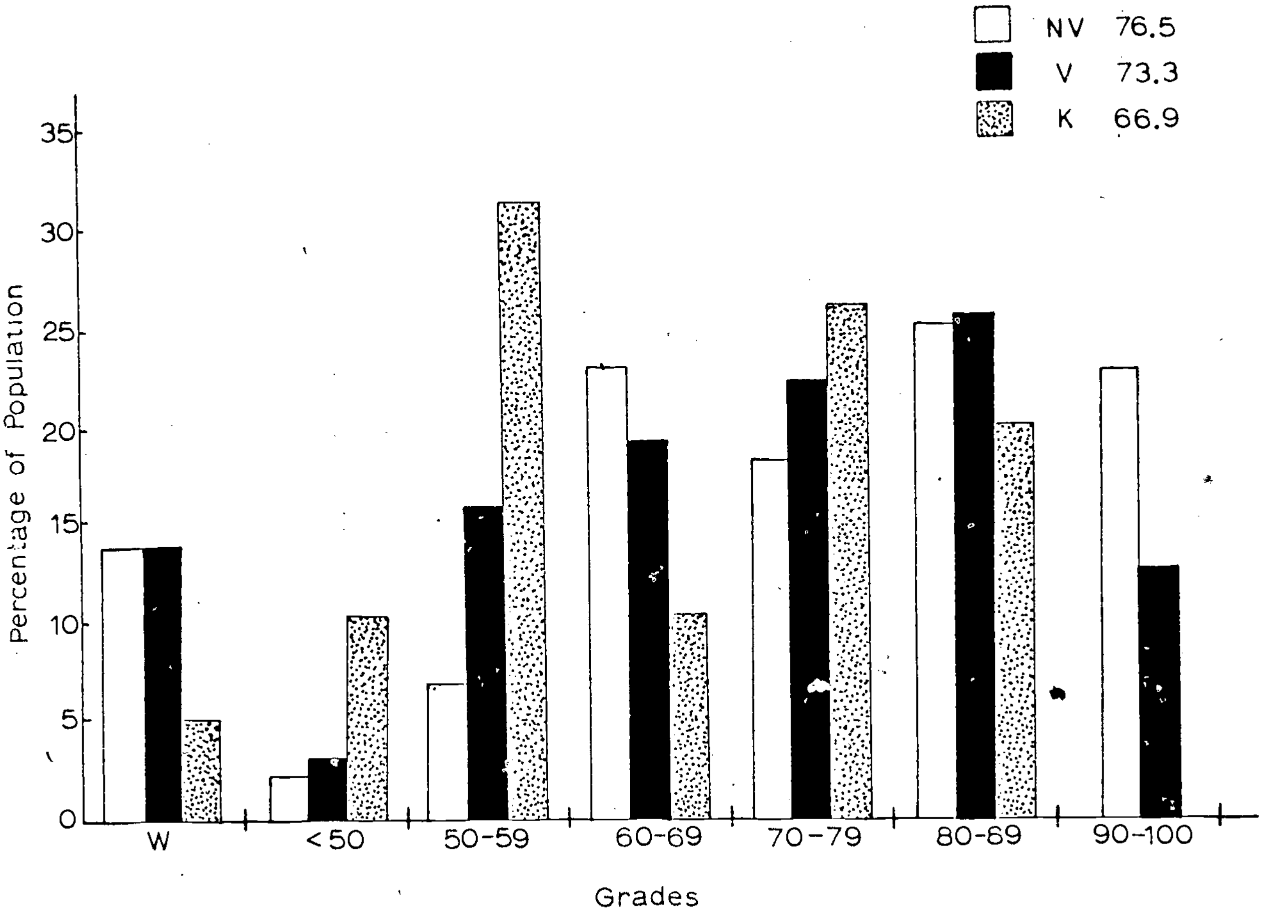


Figure 2: The performance of the entire class on the final examination. The symbol NV represents the group of students who did not volunteer to participate in the Keller Plan section; V represents those students who volunteered but were not among the randomly selected group of participants; and K represents the participants.

Several conclusions may be drawn from these final examination grades. First, the call for volunteers into a Self-Paced Instruction Program did not appear to automatically bias the sample; it was not true that only the better (or only the poorer) students applied. Rather the two populations, volunteers and nonvolunteers, seem comparable in ability. Second, Keller Plan students were at a disadvantage on the final examination especially with respect to obtaining honor grades. Whereas 2 out of 4 nonvolunteers and 2 out of 5 volunteers obtained grades of 80 and over, only 1 out of 5 Keller students did so.

I called an evening meeting during the spring semester to discuss these results and about six of the Keller Plan students attended. Prior to this meeting I had discussed the results with the tutors and we suggested several possible contributing factors for the final exam results Most of these factors were offered quite independently by the participating students who attended the meeting. These factors include a difference in the nature of the questions on the quizzes and the final examination, the grading policy and, perhaps of greatest significance, a difference between the testing situation and atmosphere in the quizzes and the final.

Apparently, the quizzes did not adequately prepare the Keller students for the final examination since considerable emphasis was placed on having the quizzes cover the behavioral objectives and/or study questions in a straightforward and at times obvious way. However, the hour exams given to the lecture class as well as the final examination did not exhaustively cover all topics in the course but involved detailed questions emphasizing the most significant parts of the course. It is likely that the quizzes did not require the same depth of understanding as did the hour exams or final. I plan to use a different textbook next year and, in collaboration with one of the tutors, am writing new Study Guides and quizzes. We are making extra efforts to make these new quizzes consistent with the testing philosophy of the other examinations in the course.

I plan also to modify the grading system from that outlined in Appendix A. Keller Plan students went into the final with 72/100 or a C safely in hand. Even if a student in the lecture class had scored 100 on all the hour exams, he would go into the final with only 60/100. The effect of this was that the Keller students did not prepare themselves for the final with the same effort as did the lecture students. We suspect that complacency contributed to the results. Next year, we plan to have 20 units and credit students with three points per unit passed.

During the evening meeting in the spring semester, the Keller Plan students commented on the prolonged discussions with their tutors after quizzes. If their written quiz answer was ambiguous or incomplete, the tutors allowed them to discuss their answer more fully in order to determine if mastery of the material had been achieved. I was aware of this development in the grading policy and because I felt it had considerable educational merit made no effort to modify it. The Keller Plan students felt that the final exam was a new and artificial testing situation. They knew more than they had written, they claimed, but had, from their point of view, inadequate opportunity to display this. Faced with the final examination results the Keller Plan students were still confident that they had learned more chemistry than their peers in the lecture section and were still highly enthusiastic about the Keller Plan approach.

The tutors and I share both their enthusiasm for this Self-Paced approach and their criticism of performance on a final exam as a meaningful way of evaluating the viability of this educational method. I feel encouraged by the results of this experiment which would indicate that Ithaca College students have the maturity and ability to do courses on a self-paced basis. Their enthusiasm for the approach and the fulfillment they derive from having mastered the material on their own are strongly positive features which prompt me to continue and even expand my use of the Keller Plan. However, I do believe that certain modifications such as supplementing written material with other modes of presentation, would be useful in aiding Keller Plan students to master the course material to the same depth of understanding as those students who have had the benefit of lectures.

Acknowledgment: The author wishes to acknowledge support from the National Science Foundation to attend the Keller Plan Workshop at MIT, Summer, 1972.

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Name: Phone Number:

| | MONDAY | TUESDAY | WEDNESDAY | THURSDAY | FRIDAY |
|---|---|---|---|---|---|
| 8-9 | | | | | |
| 9-10 | | | | | |
| 10-11 | | | | | |
| 11-12 | | | | | |
| 12-1 | | | | | |
| 1-2 | | | | | |
| 2-3 | | | | | |
| 3-4 | | | | | |
| 4-5 | | | | | |

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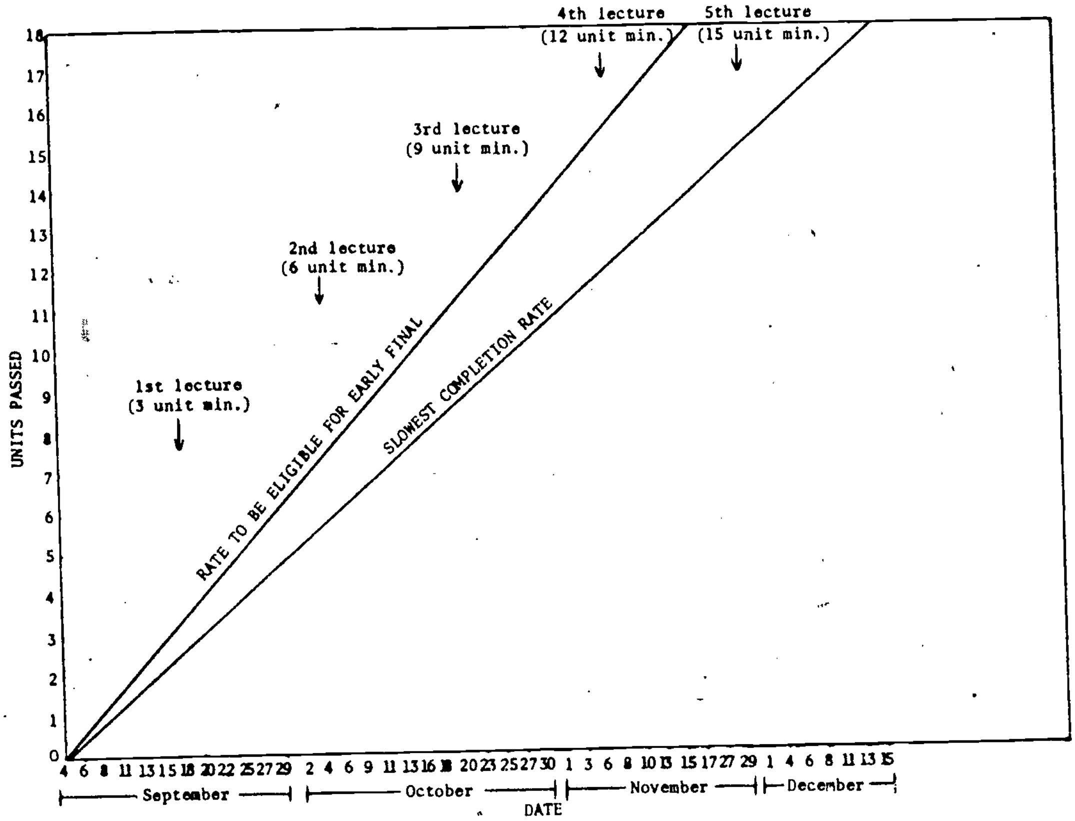
4th lecture
(12 unit min.)
5th lecture
(15 unit min.)
3rd lecture
(9 unit min.)
2nd lecture
(6 unit min.)
1st lecture
(3 unit min.)
RATE TO BE ELIGIBLE FOR EARLY FINAL
SLOWEST COMPLETION RATE
UNITS PASSED
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
September
October
November
December
DATE

16

Appendix A

Chemistry 111: Self-Paced Instruction Section Fall, 1972

R. F. Pasternack

General Information

Those of you who volunteer and are accepted into this special section of Chemistry 111 will participate in an educational experiment. To begin with, you will be banned from attending my lectures to the remainder of the class, you will work at your own pace and you will have an opportunity to ensure yourself of a C before you take the final exam. In fact, in experiments of this type at other institutions, as many as 60% of the participants earned an A in the course and almost all the rest earned a B.

The work of this course is divided into 18 units which come in a definite numerical order. You must show your mastery of each unit, by passing a short test (about 1/2 hour) before moving on to the next unit. Unlike the usual situation in college, if you fail one of these unit mastery tests, it does not count against you. You are asked to review the unit and take another test. All that matters are your successes: your failures do not continue to haunt you.

A good share of your reading and preparation for these tests may be done in the classroom. That is, your classroom will function primarily as a study hall. Some lectures will be offered during the semester (see attached schedule) but these lectures have a different relation to the rest of your work than is usually the case. These lectures, which are by invitation only, will not help you develop a mastery of the required course content. They are meant to be enrichment lectures--a form of reward to those of you progressing at what I consider to be a satisfactory pace. Students moving slower than this pace and students not in this special section of Chemistry 111 will be barred from these special lectures. In any event, attendance is not compulsory.

The teaching staff of your course will include tutors, a course manager and an instructor, me. A tutor is an undergraduate who has been chosen for his mastery of the course content and orientation, for his maturity of judgment, for his understanding of the special problems that confront you and for his willingness to assist. The tutor will answer questions for you but his main responsibility is to grade your unit mastery tests as "satisfactory" or "unsatisfactory." Ordinarily, your tutor's judgment will be law, but if he is ever in serious doubt, he can appeal to me for a ruling. The course manager will help keep records and supply you with all your study materials. Much of my work is already done; I have completed the course materials and done the various other tasks required to run such a course. I will be available for questions and to make judgments when necessary.

The most important member of the teaching staff, as yet unnamed, is you. You will do most of the teaching through use of your textbook and the "study guides" I have prepared which will be given to you as you are ready for them. You will work to achieve fairly explicit objectives, and when you think you have achieved them you will be asked to prove it on a short written test. You will have the undergraduate tutor (whom you share with nine other students) who will answer some questions for you and who will review each unit test with you as soon as you have completed it. You can move as rapidly as you like--an early final exam will be scheduled for those who prefer it and who have completed all units by November 17th.

## Course Mechanics

1. Ask the course manager to supply you with the next unit's study guide. Your task then is to achieve the objectives and/or to answer the study questions in the study guide. You can work anywhere; your dorm, beside the pool, in the Union or even in the classroom.

2. To take a test on a unit, ask the course manager for a test form. Sit in the classroom to write out your answers (closed book, unless otherwise stated). When you have finished, take your test to the tutor.

3. Your tutor is instructed to grade the test on the basis of what you wrote, and then to talk to you about your work. You can then clarify what you meant on the paper, and the tutor is allowed to cross out the old grade and enter a new one if he thinks you really understood the point of the problem. The tutor keeps your test paper for later review by the instructor.

4. If you passed, you are at liberty to return to the course manager and ask him for the next unit's study guide. If you failed, inform the course manager of this and he will note the time. Thirty minutes later you are entitled to take a retest on the unit.

Initiative in this course is yours alone. If you forget about working on the course, no one will remind you about it. Most students find it possible to establish a work schedule for themselves which insures that they make regular progress through the course. Some don't and they are the ones who fail self-paced courses. Attached is a schedule which should help you decide if you are progressing at a satisfactory rate.

## Ground Rules and Other Salient Information

1. We will collect copies of your class schedule today and set up fixed hours when tutors will be available for questions and to give tests. Most likely six hours/week will be set aside for this purpose. The location and scheduling of these quiz sessions will be posted on the door leading to my office-lab complex, 411. Any announcements and corrections to study guides will be posted on this door. Posting a notice is considered sufficient notification to students, so check the door at least once a week.

2. Grading. You earn four points for each unit you succeed in mastering. The final exam will be worth 28 points. Students achieving 70-79 points will be given a C in the course, 80-89 points a B and 90-100 points, an A. Students achieving less than 70 points will not receive credit for Chemistry 111.

   "Incompletes" will be given only to those students who have missed a substantial portion of the semester because of illness or family problems.

Appendix B

Midterm Grades

If by 5:30 p.m. on October 23rd you have passed

8 or 9 units, your midterm grade will be C

You are progressing at a satisfactory pace.

10 or 11 units, your midterm grade will be B

You are doing better than merely satisfactory work.

12 or more A You are doing extremely well.

7 or fewer NFT

You had better put in more time on your Chemistry

RFP

KELLER UNITS FOR SOME TOPICS IN GENERAL CHEMISTRY:

THE DESIGN FOR A MODULAR CHEMISTRY COURSE

by

Daniel Steffenson*, John Crump* and Dennis Gaswick*

As a first step in restructuring the general chemistry course at Albion College, three segments (modules) of the current standard curriculum have been taught using the Keller Plan Method of self-paced instruction. The remainder of the course has been taught in traditional, small lecture-discussion sections. The three segments, stoichiometry, thermodynamics, and chemical kinetics, were chosen because it was felt that this material was particularly suitable for the Keller approach. They will be used as three of the modules in a new modular curriculum to be introduced next year.

Besides reporting on the experience of integrating Keller Plan modules with traditional classes, the importance of writing careful performance objectives and explicitly testing for these objectives will be emphasized. Finally, the use of these modules and others in the design of a more flexible, modular general chemistry course will be outlined. This course will replace both the regular general chemistry course (science majors and pre-meds) and the one-semester accelerated general chemistry course (science majors and pre-meds with strong backgrounds).

The term "Keller Plan", as used here, refers to the basic teaching strategy of a personalized system of instruction (PSI) which has been thoroughly described in the literature and has been applied to courses in many different disciplines (1-4). In particular, the adaptation of this method to the teaching of general chemistry, as described in several articles in January 1973 Journal of Chemical Education (5-7), serves as an adequate model for the method used to teach these three modules with some variations as noted below. It will be assumed that the reader is familiar with the basic Keller method and it will not be described again here.

In adapting the Keller method to segments of the traditional course, certain procedures were common to all three modules. The material to be covered was divided into N Keller units to be completed by the student in N-1 weeks, where N-1 weeks was the time normally allotted for covering this material in a traditional course. Performance expectations were written and agreed upon by the authors for each unit and six different but generally equivalent quizzes were written to test these expectations. The passing level for each quiz was 85%. The student's grade for that module was based on the number of units passed, but the student could raise his grade one letter by achieving a pre-determined score on an optional exam(final) that had a one hour time limit and was given at the end of the N-1 weeks

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(Table 1). In order to allow for as much self-pacing as possible, a grace

Table 1: GRADING SYSTEM FOR KELLER MODULES

| | | | | |
|---|---|---|---|---|
| Number of Keller Units Passed | N | N-1 | N-2 | N-3 |
| Guaranteed Grade* | B | C | D | E |
| Maximum Grade Possible | A | B | C | D |
| Score on Final Exam Necessary for Maximum Grade | 90% | 80% | 70% | 60% |

*Grade guaranteed to student regardless of score on final or whether final was taken.

period of one week was available (the Nth week) for a student to complete the Keller units. Since the traditional lecture sections for the non-Keller modules were begun at the end of N-1 weeks, each student was expected to be studying new material during this grace period.

There were some differences in the operation of the three modules, primarily for purposes of pedagogical experimentation. The stoichiometry module, the first segment (three weeks) of the first semester, was taught using the Keller method to two sections (77 students) while two sections (74 students) covered the same material in the traditional course format. The students did not have a choice nor did they have prior knowledge that different teaching methods would be used in the sections. There were no scheduled classes or lectures for the Keller plan sections and both groups took the same final exam at the end of three weeks. The final exam was optional for the Keller plan students, but it was required for all students in the traditional sections, who were also given two weekly quizzes. Students in the traditional class were also given copies of the performance expectations for the Keller units.

The thermodynamics module, the first segment (four weeks) of the second semester, was taught to all four sections (108 students) using the Keller method. In addition to the written performance expectations and text material, optional lectures were given during the regularly scheduled class hours. These were not enrichment lectures as normally associated with the Keller Plan, but they were basic lectures to help the student meet the performance objectives. There were no requirements of passing a certain number of units to gain admission to the lectures. The lectures were paced to move through all of the material at an even rate in four weeks, and those students who either lagged behind or worked ahead of this pace lost much of the benefit of the lectures.

The chemical kinetics module, the third segment (two weeks) of the second semester, was to be taught using both the Keller and the traditional approach. The students had the option of choosing which method to use, but only 2 of 108 opted for the traditional approach. The lectures for these two students were also available for the Keller students and served the same function as the lectures in the thermodynamics module.

The results of the students' achievements in these three modules are summarized in Tables 2-4. In addition, after completion of the kinetics

Table 2: COMPLETION RATE AND GRADE DISTRIBUTION FOR THREE KELLER PLAN MODULES

STOICHIOMETRY

| Last Unit Passed | No. of Students | % of Students | Ave. No. of Quizzes to Pass | Module Grade | % Students with Grade* | Course Grade* |
|---|---|---|---|---|---|---|
| | | | | A | 27.6% | 17.6% |
| 4 | 51 | 66% | 1.45 | B | 43.4 | 46.1 |
| 3 | 16 | 21 | 1.39 | C | 17.1 | 25.6 |
| 2 | 3 | 4 | 2.23 | D | 4.0 | 11.0 |
| 1 | 3 | 4 | 2.07 | E | 7.9 | 0 |
| 0 | 4 | 5 | | | | |
| Totals: | 77 | 100% | | | 100% | 100% |

THERMODYNAMICS

| Last Unit Passed | No. of Students | % of Students | Ave. No. of Quizzes to Pass | Module Grade | % Students with Grade* |
|---|---|---|---|---|---|
| | | | | A | 13.9% |
| 5 | 71 | 65.7% | 2.01 | B | 52.8 |
| 4 | 22 | 20.4 | 1.66 | C | 19.4 |
| 3 | 7 | 6.5 | 1.81 | D | 8.3 |
| 2 | 3 | 2.8 | 1.87 | E | 5.6 |
| 1 | 3 | 2.8 | 1.42 | | |
| 0 | 2 | 1.8 | | | |
| Totals: | 108 | 100% | | | 100% |

KINETICS

| Last Unit Passed | No. of Students | % of Students | Ave. No. of Quizzes to Pass | Module Grade | % Students with Grade* |
|---|---|---|---|---|---|
| | | | | A | 14.6% |
| 3 | 72 | 69.9% | 1.7 | B | 58.2 |
| 2 | 13 | 12.6 | 1.9 | C | 9.7 |
| 1 | 3 | 2.9 | 2.9 | D | 2.9 |
| 0 | 15 | 14.6 | | E | 14.6 |
| Totals: | 103 | 100% | | | 100% |

*First semester grade distribution for all students enrolled in the second semester.

Table 3: PERFORMANCE ON STOICHIOMETRY FINAL EXAM

| Grade on Final | Percent of students: Keller Method (77 students)* | Traditional Class (74 students) |
|---|---|---|
| 90-100 | 28% | 13% |
| 70-89 | 27% | 35% |
| 50-79 | 9% | 30% |
| < -50 | 20% | 22% |

* 16% of the students did not take the final.

Table 4: NUMBER OF UNITS COMPLETED VS GRADE ON STOICHIOMETRY FINAL EXAM

| Grade on Final | 4 units | 3 units | 2 or less units |
|---|---|---|---|
| 90-100 | 54% | 11% | 0% |
| 70-90 | 40 | 34 | 9 |
| 50-70 | 6 | 28 | 18 |
| < -50 | 0 | 28 | 72 |
| Number of students | 35 | 18 | 11 |

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module, a questionnaire was used to assess various aspects of the students' experience with the Keller Plan. The results of this questionnaire will be mentioned in the following discussion.

The success of these modules can be measured in several ways. The students covered difficult material and completed a high percentage of it at a high level of performance, the results indicate that they learned more than in a traditional class, they themselves thought they learned more, they liked the Keller method, and they would like more of the course taught this way. The entire chemistry staff felt that the students were given material at a deeper and more difficult level than in the past and that the students worked harder and learned more than they would have in a traditional class covering the same material.

There is support for the above assertions in the data and in the results of the questionnaire. In Table 2 it can be seen that for each module 65-70% of the students passed all of the units at the 85% level (B work) and an additional 15-20% passed all but one unit (C work). This is a completion rate that at least equals what one would expect in a traditional class. The level of difficulty requires a much more subjective analysis, but after the results of the stoichiometry module, which was written at the level of the text (Masterton and Slowinski) and paralled the traditional class, the staff felt that the Keller students were not challenged enough and the level of expectations for the thermodynamics and kinetics modules was increased. In any case the opinion of the authors is that a greater amount of material at a greater depth was covered by the students in the thermodynamics and kinetics modules.*

The assertion that students learned more is supported by the data in Tables 2 and 3 for the stoichiometry module. The Keller students did generally better on the common final than did the traditional students, especially at the 90-100% level. From Table 3 is is clear that those Keller students who had finished all four units before the final did considerably better than any other group while those Keller students who had covered less than half the material did considerably poorer than any group. Similar comparisons are not available for the other two units because all the students were required to take thermodynamics using the Keller Method and all but two of them opted to take the kinetic module the same way.

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*The approach used for the thermodynamics module was considerably different than that found in standard texts. It was based on notes written by Dr. Norman C. Craig of Oberlin College for his students and for an NSF Chautauqua Type Short Course for College Teachers (sponsored by AAAS and attended by one of us (DMS)). The approach originated with Dr. Henry Bent and his book The Second Law (8) and descriptions of the method have appeared in the Journal of Chemical Education (9,10). This is an elegant method of teaching thermodynamics that worked extremely well with our students using the Keller approach.

The students also felt that they had learned more chemistry with the Keller approach. On a scale where 5 meant "definitely more with the Keller Method" and 1 meant "definitely more with the lecture method", the average student response was 3.8 for "understanding of material," 3.9 for "sense of achievement," and 4.0 for "time spent on chemistry". Also, Table 5 shows that the study sources most closely associated with the Keller method were by far the most useful in learning the material.

Table 5: STUDENT EVALUATIONS OF KELLER STUDY SOURCES

The following responses were obtained from questionnaires distributed following the kinetics module.

5 = very useful    1 = not used at all

| | Study Source | Ave. Response | Most used method* Thermo | Kinetics |
|---|---|---|---|---|
| A. | Performance Expectations | 4.46 | 50.0% | 41.4% |
| B. | Having Quiz Graded | 4.23 | 30.9 | 39.0 |
| C. | Practice Problems | 3.77 | 7.1 | 8.0 |
| D. | Lecture | 3.06 | 6.0 | 4.6 |
| E. | Text Material | 3.18 | 4.8 | 6.9 |

*Students were asked to choose the top three study sources and rate them as most useful, more useful, and useful and the Table lists the % of the questionnaires listing that study source as most useful.

The students' subjective response to the Keller modules was overwhelmingly positive. For example, even though only half of them had taken the stoichiometry module, 78% would have preferred to take the thermodynamics module using the Keller rather than the lecture method. After requiring all of them to use the Keller method for thermodynamics, the students were then given the option of taking kinetics by either method, and 98% (all but 2 of 108) chose the Keller method. After completing the kinetics module, students were asked what percentage of the general chemistry course they would like to have taught using the Keller method, and they responded:

100% of course -- 36%
75% of course -- 24%
50% of course -- 31%
25% of course -- 5%
0% of course -- 4%

Over 90% would prefer a course that is at least 50% taught using the Keller method, but only a little more than a third would prefer a complete Keller course.

There are no quantitative data to support our feelings that the Keller modules were quite successful. However, the departmental staff unanimously agreed that we had taught the students far more thermodynamics and kinetics, and at a deeper level, than ever before in general chemistry. A great deal of the success with thermodynamics may be ascribed to the new and different approach mentioned above. This is a far superior way to teach thermodynamics in general chemistry. However, the staff feels that this approach would not have been so successful if it hadn't also been taught using the Keller method. The Keller method kept students from mvoing on to more difficult topics until they had mastered the basics, and this was particularly useful in getting slower students through the material with some sense of success.

Another measure of the success of the Keller modules is what they have done for individual students. For example, two students did B work in the stoichiometry module and then failed the rest of the first semester course. One student, when trying to decide whether to take the kinetics module in the Keller or the lecture section said: "I guess I'd better do the work and take the Keller module so I'll learn it." That pretty well sums up how the department feels the Keller modules worked for most of the students.

Of course, not all students responded equally well to the Keller modules. The most troubling were those students who never attempted any Keller quizzes or started so late that they only completed one or two units. Table 2 indicates that for the stoichiometry and thermodynamics modules, this was only about 10 students. The number was higher for the kinetics module because: 1) We errored in making the first unit too difficult (see Ave. quizzes attempted in Table 2). 2) We required students to have passed the first unit by the end of the allotted time (two weeks) in order to continue taking quizzes on the other units during the one week grace period. Unfortunately, we found that it was often the same students who failed to get started on each module. Even with a fresh start and the knowledge that they had already failed an earlier portion of the course, these students still failed to get started on the Keller units. In spite of this, when given the option to take the kinetics module in a lecture class or on the Keller plan, some students who had yet to pass a Keller quiz in the earlier two units, still opted for the Keller method.

We also encountered a problem in obtaining enough students to tutor and grade quizzes. This may be one of the real disadvantages of teaching only part of the course on the Keller plan. The first students in the course to pass the units (the best source of tutors) are reluctant to tutor until they have the confidence of passing two or three units. By then the module is over half finished. They are also reluctant to tutor during the grace week period when new material is being taught in the traditional class. It is more difficult to get upperclass students to tutor because tutoring is not a part of their weekly schedule throughout the semester, so they do not plan their time with tutoring in mind and are then too busy to tutor when a Keller module begins. The only other source of tutors in an undergraduate liberal arts coblege is the chemistry staff. When faced with only a few weeks of grading Keller quizzes, the staff has a tendancy to decide that doing most of the grading themselves is not too big a burden and then proceed to overwork themselves.

The tutoring problem is a difficult one, but one that must be solved if the Keller approach is to be used with any sense of efficiency. We hope to overcome this problem next year by giving one staff member responsibility for recruiting and organizing the student tutors as his share of contribution to the teaching of the course.

One other disadvantage in using the Keller approach on short modules is the limitation on self-pacing by the students. This is an important feature of the Keller method, and the one most diminished by the modular approach. The addition of the extra week was intended to alleviate this problem, but many students wanted to finish all of the units before the final and the extra week was of no use to them. When asked, "could you control the rate at which you completed each module, ie. were you able to 'self-pace' the rate at which you covered the material in the module," the average reply was 3.56 for the thermodynamics module and 3.22 for the kinetics module where 5 meant definitely yes and 1 meant definitely no. Only about 20% of the students felt that they definitely could self-pace the material.

Even though there are disadvantages in the modular use of the Keller method, there are also strong advantages that make this approach very attractive. For example, some material is either more suited or more readily adapted to the Keller method. The critical feature of the Keller approach, in determining suitability, is the use of performance objectives and testing only to the quality of performance on those objectives. The assumption is that there are times when the emphasis is on learning a skill, e.g. solving stoichiometry problems, determining rate laws and rate constants, etc., and times when the emphasis is on depth of understanding and extrapolation of principles or models into new areas, e.g. using atomic structure and periodic properties to understand and explain the observed chemistry of the elements. Even some of the critics of performance objectives admit that there are areas of learning when they are useful and appropriate (11-13). One of the most thoughtful critics, Jay Young (11), puts the whole question in perspective, and calls for intelligent use of behavioral objectives wherever it seems appropriate.

Another advantage of the modular approach acts somewhat as a trade-off to the loss of self-pacing. With short modules of 3-4 weeks, students who fall behind or cannot pass the units get a fresh start on new material. Students may fall behind in a module for any number of reasons. For example, the material in a module may be too hard for many students to pass. Such mistakes or problems need not spoil the whole semester. Also the opportunity for a fresh start allows a greater opportunity for the use of traditional lectures and discussions since students start each module together and the majority tend to progress at similar rates. The lectures were particularly helpful for certain students in the thermodynamics and kinetics modules. Modules offer an opportunity not present in a standard Keller course where lectures are used only for enrichment and as a reward for keeping up to date on the units.

Keller modules offer one further advantage to someone planning to introduce the Keller method into a course. Keller materials can be developed more slowly over an extended period of a year or two. The development of a good Keller course is a demanding and time consuming task, especially the writing of performance expectations and unit quizzes. Unless one has release time from other teaching duties or begins well in advance, it is almost impossible to keep ahead of students and write materials as the semester progresses without compromising the quality of the material. By writing expectations and quizzes for one or two modules a semester, one can produce better material, gain feedback on the material with less risk to the overall quality of the course, and perhaps write supplementary material or sample problems for the modules that make them less dependent on a particular text. Finally it is easier to convince other members of your staff to commit part of the course to the Keller method and thus get them to participate, if not in the writing, at least in the judging of the quality of the materials.

No matter how the Keller Method is used in a chemistry course, the authors have become convinced that the real key to the success of the method lies in writing careful and precise performance expectations and explicitly testing to these expectations. Part of this conviction grows out of our experience with the Keller modules this semester, but much of it stems from a week-long workshop in instructual design sponsored by the Associated Independent Colleges and Universities of Michigan (AICUM) and held on the Albion College campus last summer. In this workshop each of us began working on one of the modules in close consultation with behavioral and educational psychologists who were experienced in the design of programmed learning, self-instructional courses, etc. Our purpose was to learn how to write valid behavioral objectives for general chemistry and how to test to those objectives. It would be impossible here to distill what we learned that week, but one or two important points are worth making.

The resource persons for the workshop constantly prodded us to make our expectations more explicit and to place definitive limits on the breadth and depth of knowledge required to meet the expectations. The goal is to write expectations such that three other chemistry professors would necessarily agree quite precisely on what a student would have to do to satisfactorily meet that expectation. Secondly, these three chemists should be able to agree that if the student meets the expectation, he will have learned what one wanted him to learn about that portion of that material.

A similar approach should be used in writing the Keller quizzes for the expectations. These same three chemists should agree that a correct response to a quiz question demonstrates an acceptable knowledge of the material. These chemists should also agree that all the quizzes for a particular unit are generally equivalent but not identical to the point of appearing to be the same question with different numbers. Furthermore, these chemists should generally agree that by passing the unit quizzes, a student does indeed know and is competent with all of the material (at the 85-90% level). This requires considerably more testing than the typical weekly quizzes or periodic hour exams of the traditional course, but that is one of the key features of the Keller method, and it is often subverted by people claiming to use the Keller approach.

At this point, some specific examples may be helpful. An expectation such as "Be able to derive valid rate laws for a reaction" is inadequate in that it does not specify the type of information from which the student will be expected to derive a rate law. On the other hand, the expectation "Given the initial rate of reaction (or data from which it can be calculated as in the expectations above) at different concentrations of A, B, etc..., be able to derive a valid rate law for the reaction" provides some limits to the problem and some indication of a successful procedure to follow in solving the problem. The quiz then provides the promised data and asks the student to derive the rate law.

By way of further illustration, we have examined some of the recent commercially available Keller-type course materials which include performance expectations. All too often, phrases such as the following appear:

> "Demonstrate how the ____ theory explains ____"
> "Use the ideal gas equation to solve problems
> involving gases"
> "Describe the limitations of ____"

We submit that these expectations are inadequate in that they do not specify limitations on breadth, depth or extent of material covered. In most cases, a theoretical explanation can be "demonstrated" at a variety of levels, ranging from a simple, qualitative level to a very sophisticated, mathematical analysis. If this be the case, how can three chemists <u>necessarily</u> agree whether a student has adequately demonstrated his competence in meeting this expectation? Similarily, the ideal gas equation can be used in many different kinds of problems involving gases beyond the simple calculations of gas phase stoichiometry. Is the student really expected to be able to solve all such problems? In both of these instances, the author of the expectation probably had something quite specific in mind, but has not included it in the written statement. In short, action verbs such as "describe" and "explain" and their close relatives (understand, know, discuss, etc.) rarely belong in performance expectations because they do not ask the student to <u>do</u> something which can be clearly defined.*

Hopefully the above discussion has provided some insight into the difficulty of writing valid performance expectations and quizzes and how to improve in this area. The degree to which carefully written expectations and quizzes can facilitate learning can be judged from the responses of students to the questionnaire at the conclusion of our Keller modules. As mentioned above (Table 5), students rated the performance expectations and having their quizzes graded as their two most useful study sources. Furthermore, on a scale where 5 meant "definitely yes" and 1 meant "definitely no", the average student response to "Were the expectations clear?" was 4.26 for thermodynamics and 3.75 for the kinetics module. To "Did the quizzes measure your understanding of the material?", the response was 4.18 for thermodynamics and 4.08 for kinetics. Since the ultimate test of the materials is how well

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*After this paper was written, a similar statement concerning performance expectations has appeared in a Report of the High School Subcommittee of the Curriculum Committee of the Division of Chemical Education of the American Chemical Society (J. Chem. Educ., <u>50</u>, 257 (1973)).

they work with your students, we feel that we have achieved some measure of success with these Keller modules.*

As indicated at the outset, we intend to redesign our entire general chemistry course on a modular basis next year. Some of the modules will be taught using the Keller plan and others in traditional lecture sections. The general outline of the course consists of 3-4 week modules that cover most of the material in the present course.

| Semester I | Semester II |
| --- | --- |
| Stoichiometry (Keller plan) | Thermodynamics (Keller plan) |
| Atomic and Molecular structure | Solutions, Phases, and Phase Equilibria |
| Periodic Properties and Descriptive Chemistry | pH and weak Acid-Base Equilibria (Keller plan) |
| Gaseous Equilibria and Kinetics (Keller plan) | Electrochemistry |

In addition, students who would have taken the one semester accelerated general chemistry course will cover in one semester all the first semester modules plus the two Keller modules listed under Semester II. They will then proceed to advanced courses in Semester II. To facilitate their progress, several equivalent final exams will be written for each module and students may test out of that module by achieving a predetermined score on the exam.

The course is only the first approximation of a course that will eventually have several additional modules. We hope to designate certain modules as prerequisites for organic chemistry and include others as prerequisites for a chemistry major. Some modules would be optional and students could choose different ones depending on background and interest. In addition we would like to offer the basic modules more than once each term to increase the flexibility of the course. Eventually the laboratory will also be offered in modular form to allow more flexibility in meeting the various needs of the student.

At this time we can only speculate as to what will happen after next year, but we intend to continue to develop Keller modules and to use them along with traditional classes.

*Sample Keller units and quizzes from these modules may be obtained by writing directly to the authors.

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# PROGRAMMED SELF INSTRUCTION IN FRESHMAN CHEMISTRY

by

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## Introduction

Several problems and special conditions have occurred in the first semester course of freshman chemistry which hinder both students and professors. Two of these are: unequal backgrounds from high school, and wide-spread differences in learning ability as well as in interest and motivation. It is difficult to lecture to such a diverse audience without boring some and inundating others. The class is also unpleasant from the student's viewpoint if he is faster or slower than the lecturer's pace.

In an effort to correct some of these inequities a self-paced course was developed based on the Keller (1) plan. This was accomplished with helpful discussions with Dr. J. M. White (2). However, several significant changes were made from the Keller plan. These modifications and the results of three sections taught in this manner are presented here.

## Course Mechanism

During registration for the fall semester (1972), students were informed of three special chemistry sections. In this sense students were screened or selected. Those who had a strong background in chemistry or felt that they had sufficiently developed study habits were encouraged to enroll. Perhaps it would be more accurate to say that ill-prepared students were discouraged from participation. This selection process should be kept in mind when evaluating final data. In retrospect, the authors feel that screening was helpful if for no other reason than to give the student a choice and to let him accept some responsibility.

The text (3) was used with minimal supplemental notes. It was felt that a reasonably good text should suffice, and therefore the study guides were not as complete as for other Keller courses. That is, a detailed outline of required information (problem types) was not given. The problems at the end of the chapter were recommended and from these, in part, the examinations were modeled.

The first 13 chapters of the text were covered but not in the given order. The most important material (8 chapters) was used in units 1-7 and a minimum of 7 units was required for a grade of "D". This was done to ensure that each person passing the course received training in those subjects which serve as prerequisites for the second semester course. These topics included: matter, measurement, liquids, solids, solutions, atomic theory, chemical bonding, gases, and ions in solution. The topics for units 8-10,

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which could be considered "optional" were: kinetic theory (covered earlier somewhat), molecular theory, oxidation, hydrogen, water, and active metals.

Grade assignment was complicated by the inclusion of the laboratory as part (25%) of the grade in addition to the final exam (25%). As a result, minimum requirements were established with respect to the number of units passed as follows: A-10, B-9, C-8, D-7, F-6 or less. The exams were 30 minute, 10 question, multiple-choice; and a passing grade was 90% or one allowable error. For each unit three different exams were available. After three failures the student was allowed to repeat the series. The grading was done in the presence of the student as soon as possible after completion. The verbal grading occasionally resulted in a passing grade of 85%. Unfortunately, late in the course it was learned that correct answers to the quizzes were being recorded and passed to other students. Therefore, verbal grading was limited to discussion of general problem types.

The actual class period (1 hour 20 minutes) was allotted to examination, grading, and tutoring. Three undergraduate tutors were employed in each class of approximately 30 students. In a large lecture room the lecture desk was used to distribute the quizzes and answer sheets and to grade the completed exam. The front of the room was utilized for individual tutoring while exams were taken in the back under the supervision of one tutor.

## Course Statistics

Three sections were taught with a total final enrollment of 75. The final grade results of both PSI and lecture classes are given in Table I.

TABLE I

GRADE DISTRIBUTION
(percent of class)

| | PSI-1 | PSI-2 | PSI-3 | Lecture | Lecture | Lecture |
|---|---|---|---|---|---|---|
| A | 12 | 22.6 | 27.3 | 9.4 | 6.8 | 7.7 |
| B | 32 | 25.8 | 13.6 | 17.0 | 18.2 | 12.8 |
| C | 20 | 32.3 | 36.4 | 32.1 | 36.4 | 30.8 |
| D | 4 | 6.5 | 4.5 | 18.8 | 25.0 | 33.3 |
| F | 32 | 12.8 | 18.2 | 22.6 | 13.6 | 15.4 |

There is some difficulty in comparing this grade distribution with those in lecture courses since the grades actually have different meanings because of the different requirements. From these data the only consistent pattern is a higher percentage of A and a lower percentage of D for the PSI method.

Perhaps it is more realistic to look at scores from a departmental final exam given to all first semester chemistry sections (Table II). Although two of the PSI classes showed the highest averages they were not significantly higher than the lecture classes. Also one PSI average was among the lowest lecture averages. This is not a favorable indication for the PSI method, particularly in view of the fact that the better students were selected for this trial.

TABLE II

FINAL EXAMINATION SCORES

| | No. Students | High | Low | Average |
|---|---|---|---|---|
| PSI 1 | 27 | 78 | 38 | 56.9* |
| 2 | 27 | 92 | 42 | 65.6 |
| 3 | 21 | 96 | 32 | 64.8 |
| Lecture 1 | 79 | 88 | 24 | 54.8 |
| 2 | 59 | 92 | 34 | 61.2 |
| 3 | 119 | 92 | 32 | 63.3 |
| 4 | 34 | 80 | 36 | 54 |
| 5 | 67 | 88 | 24 | 56 |
| 6 | 64 | 82 | 24 | 53.6 |
| 7 | 55 | 86 | 34 | 60.5 |

*It should be noted that in this class the unit quizzes were given as "open book" but this was not permitted on the final examination.

## Advantages

There are a number of advantages to the system described here. Some were obvious and expected; others were pleasant surprises. Also some were pedagogical in nature and others were more personal for both students and professors.

It was noticed from the professor's viewpoint that personal contact was increased, and, as a result, names and faces were more quickly associated. It was difficult for a student to escape notice by the instructor as occasionally happens in a large lecture course.

Students were found to readily accept the responsibility for their progress or grade or lack of either. There were few and infrequent discussions of how the course was unfair. Even those who were failing the course quietly accepted their position. This may be one reason for yet another effect: the student and professor seem to be more like allies rather than enemies in the battle for knowledge.

Another of the expected results was that the students developed their own study methods which should aid them in other courses. Those who were not able to do this were readily apparent. It was also no surprise that the fast student benefited most from this approach. They were most enthusiastic in their support of this method.

Finally, even though the initial work in preparation of this course was considerable, it would be easier and better on a second or third repetition. There were several minor but very helpful changes which became obvious as the course progressed. During the second offering there would be time for improvement. Furthermore, the faculty could devote more time to individual students.

## Disadvantages

The most serious problem encountered was one of classroom logistics. During the first few weeks the process could be described as chaotic, at least for the professor in charge. There were 30 students each clamoring for a different quiz, 3 tutors not knowing what to do, and one professor attempting to organize the confusion, give out proper exams, and grade those being returned without letting other students know the answers. Some of this strain was alleviated by using multiple choice quizzes and by restriction of student access to the grading area.

Since only supplemental study guides were supplied, the textbook assumes a paramount importance. The chapters must be reviewed in detail with important information noted and optional or unimportant sections deleted. In addition, the problems must be worked through to seek out errors.

Although there is more contact with most students, a few students seem to disappear. Since class attendance is not required, it is essentially impossible to seek out a student for some specific purpose, such as to discuss his performance. In this same sense it is difficult to motivate the marginal student. It can be done effectively, of course, on an individual basis, but first the student must appear in class and approach the professor, unlikely actions for the apathetic student.

In solving one problem by instituting multiple choice exams another was created, that of making the answers easy to remember and pass to other students.* This was discovered nearly 3/4 of the way through the semester at which time the grading procedure was changed so that the student could not see which problems were missed but was told the problem type.

Finally, students felt that they were handicapped somewhat by not having old exams to use for review prior to the final exam. Those that finished early in the semester were allowed to look back through copies of the exams; but, of course this was impossible with the whole class.

## Student Evaluation

A questionnaire was given to each student completing the final exam. This was essentially the same as that used by White, et. al. (2) (except for the addition of questions 1 and 2), and is given with results in Table III.

Some significant differences are obvious between these data and those of White, Close and McAllister. Less than half of our students thought that this method allowed more student-teacher interaction (question 4). Only 2/3 of them liked the method compared to 93% for White; and just over half learned more this way than in a lecture (96% for White). The only two questions where our percentages were higher were 9 and 10 dealing with the fairness of the grading process.

*This cheating occurred in other departments utilizing the Keller method and became the principal objection by students to the method.

TABLE III

Student Evaluation of PSI Course

| | | % Favorable | % Neutral | % Unfavorable |
|---|---|---|---|---|
| 1. | Do you consider your chemistry training prior to this course to be: good fair poor | 28.6 | 44.4 | 27.0 |
| 2. | Would you take another course taught in this manner? yes maybe no | 47.6 | 30.1 | 22.2 |
| 3. | One of the goals of the course was to assist students in establishing study habits which were more regular than normal. This course was: (successful, not successful) in this regard. | 80.6 | -- | 19.3 |
| 4. | Another goal was to allow more student-teacher interaction than normal. The course was (successful, not successful) in this regard. | 41.1 | -- | 58.9 |
| 5. | I (like, dislike, am neutral about) the general method used in this course. | 66.7 | 17.5 | 15.9 |
| 6. | The method (helped, did not help) me to rely more fully on my own study for understanding. | 88.5 | -- | 11.5 |
| 7. | I felt that what was expected of me was (clearly, not clearly) stated. | 81.7 | -- | 18.3 |
| 8. | I felt the grading scheme was (fair, unfair) | 82.3 | -- | 17.7 |
| 9. | I felt the grading process itself was (even-handed, biased). | 96.6 | -- | 3.4 |
| 10. | I (liked, disliked) the oral part of the grading. | 97.7 | -- | 2.3 |
| 11. | I feel I learned and understand (more, less, nearly the same) about the subject matter of this course than I would if it had been given by the traditional lecture method. | 55.5 | 22.2 | 22.2 |

12. Compared with the effort I usually put forth in a course, my effort in this course was:

well above average 14.4% above average 54.8% average 25.8
below average 3.2% well below average 1.6%

13. Compared with all the courses I have had, both in high school and in college, this course was:

well above average 9.8% above average 45.9% average 31.1%
below average 11.5% well below average 1.6%

Finally the general rating of the course (question 13) was lower here than reported earlier (2).

In Table IV, the student comments for course improvements are given.

TABLE IV

| | COMMENTS | % |
|---|---|---|
| 1. | Increased use of class discussions, lectures and films. | 20.9 |
| 2. | More and better tutors. | 16.3 |
| 3. | More opportunities to take exams. | 16.3 |
| 4. | Let an 80% grade be a passing score. | 13.9 |
| 5. | Improved study guides and text. | 9.3 |
| 6. | Limit class participation to only qualified students. | 7.0 |
| 7. | Allow skipping a failed unit. | 4.7 |
| 8. | Have fewer units each with more questions. | 4.7 |
| 9. | Provide more student-professor contact. | 4.7 |
| 10. | Require class attendance. | 2.3 |

The item most mentioned was more use of lectures, discussions and films. Although lectures were planned, none were executed due to time limitations. A few films were utilized.

Some classes were given on Tuesday/Thursday. This allowed only two quizzes to be given per week which was too restricting (question 3).

It was interesting that 7% felt that it was most important to limit enrollment to well-qualified students.

Of course, there was some response to lower the passing score, allow skipping units, etc., but these were felt to be unacceptable for the most part.

## Conclusions

After one semester of three sections by this modified Keller plan the instructors are less than enthusiastic. The best general conclusion is that it is no worse than the lecture process. The final exam averages, perhaps the most meaningful data, are not convincing in their support of this modification of the Keller method.

Although the process would be easier the second time, several additional changes are needed. The most important of these is to have computer generated quizzes to eliminate cheating while maintaining ease of grading.

Secondly, graduate students should be utilized as assistants rather than undergraduates. However, this is not possible with the present numbers available and the need for laboratory instructors.

Finally, students should be even more carefully screened to permit only science majors with a good background and motivation to enroll.

No plans exist presently to offer this same course or a different one by this method.

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SELF-PACING: EVANGELISM AND EFFECTIVENESS

by

George Gilbert*

## Introduction

The evangelistic manner in which new methods of teaching develop and are promulgated by the enlightened to those seeking 'light' is both valuable and of some concern. The tendency toward more student initiative and responsibility for the process of education is one such trend, another related pattern is that of self-pacing learning. There are many ways in which these trends evidence themselves both in the lecture and laboratory portions of chemistry courses. The kinds of pressures which cause different faculty wishing to follow such trends to join in and establish a teaching procedure in keeping with local traditions and available resources varies. These pressures include the decreasing interest and antipathy towards pure science and technology, and also the increasing amounts of information to be understood and/or stored tax our facilities and course patterns. More significant still is the attitude that we can and must do a better job of preparing students both in backgrounds in the various areas of chemistry and towards becoming independent thinkers and developers of new knowledge. Personally, my attitude is strongly influenced by the concern that we establish early in a student's career the expectation that he or she will be required not only to have substantial material available or know its location but also that a student while being educated individually must effectively demonstrate his/her understanding of the principles and concepts discussed--both in lecture and in the laboratory.

I learned of this particular technique of teaching through my colleagues in psychology and felt its application to courses in chemistry was worth a try. Through the assistance of these colleagues I obtained resources which outlined the goals and procedures used by certain faculty--in psychology. With this procedural information I attempted the technique with a small, off-semester course of 11 students (the second semester of our two-semester freshman course).

## The Fall Semester Course

The basic information concerning this course is given in Figure 1 and includes the texts, number of study units and tests, number of students, laboratory procedure and the grade distribution.

The project-style laboratory procedure used is consistent with my teaching philosophy which stresses the involvement of the student in developing the laboratory procedure and habits of observation while allowing minor digressions or repetition of work if such seems advisable. The laboratory was not offered via the Keller plan nor integrated into the

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FIGURE 1

| | | |
|---|---|---|
| Chemistry 201 | 5 semester hours | 3 lectures, 2-three hour labs |

Texts

"Chemical Equilibrium" by Allen J. Bard (1966), Harper and Row.

"Fundamentals of Chemistry" by Brescia, Arents, Meislich and Turk (1970), Academic Press.

Number of Students - 11

Assistants - Two senior chemistry majors

Study Units - 13 - no review units

Exams - Final exam only

Laboratory Procedure - Project lab using modified format of Spittlegerber, Mac Lean, Neils, J. Chem. Educ., 48, 330 (1971).

Point Distribution -

| | |
|---|---|
| study units | 520 |
| laboratory | 300 |
| final exam | 180 |
| | 1000 |

Grades - 5 A's, 5 B's, 1 C

lecture directly but constituted a separate segment of the course. This separation has subsequently been formalized by designating the laboratory by a different number.

The study units for this first course were prepared during the summer and checked for readability by one of the senior level assistants who commented freely and constructively. Not all the units were written, in keeping with good Keller tradition that change or modifications are more likely if not all the units are completed. No major changes were made, however, as the later units were completed during the early part of the semester.

This class was particularly cohesive, in large part due to the six hours plus of lab together each week and the small size of the group, and shared ideas and experiences well in both the self-paced and laboratory work. As a consequence when I sought student assistants for the spring semester course, the students were virtually unanimous in volunteering to assist.

## The Spring Semester Course

The spring semester course was a 3-credit, pre-sequence offering which prepared weaker students for the regular sequence. Since there was no laboratory it did not satisfy the Denison science requirement. The usual enrollment in the course had been 35 to 55 students but this semester 81 students were initially registered of which 71 finally completed the course.

The 14 study units required were prepared during the January Term and first part of the semester and the suggestion of a mid-term as well as a final by the earlier group of students was included. The pertinent information concerning text, number of students (enrolled and completing the course) as well as the grade distribution is given in Figure 2.

FIGURE 2

Chemistry 108 3 semester hours 3 lectures, no lab

Text
"College Chemistry", 3rd edition, by Keenan and Wood (1957), Harper & Row.

Number of Students - enrolled: 75 completed: 71

Student Assistants - 9

Study Units - 14

Exams - mid-semester, final

Point Distribution - study units 560
mid-semester 200
final 240
1000

Grades - 26 A's, 18 B's, 19 C's, 3 D's, 3 F's

The student reaction via evaluations varied from excellent to very bad. One cause of the negative reaction encountered was the inability to offer another section via lecture and the most negative responses were noted from students who wanted this option. Figures 3-9 give graphical representations of student responses to various questions on the evaluation form used. Attempts to correlate the overall response (excellent to very bad) with the reaction to other items was poor except for the attitude toward the text.

FIGURE 3

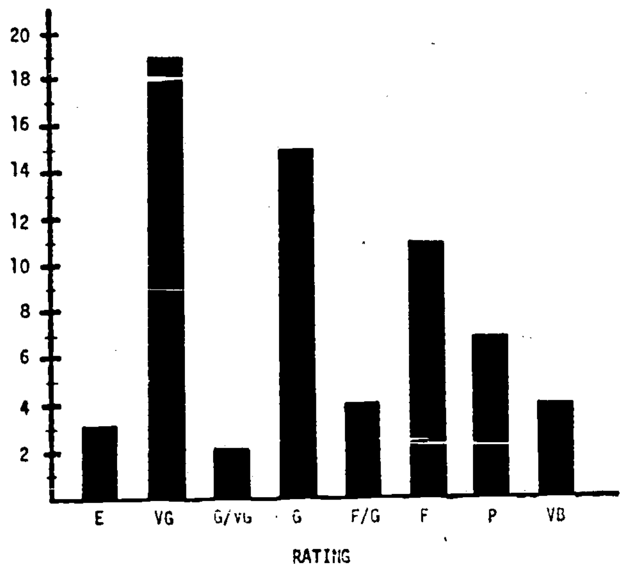
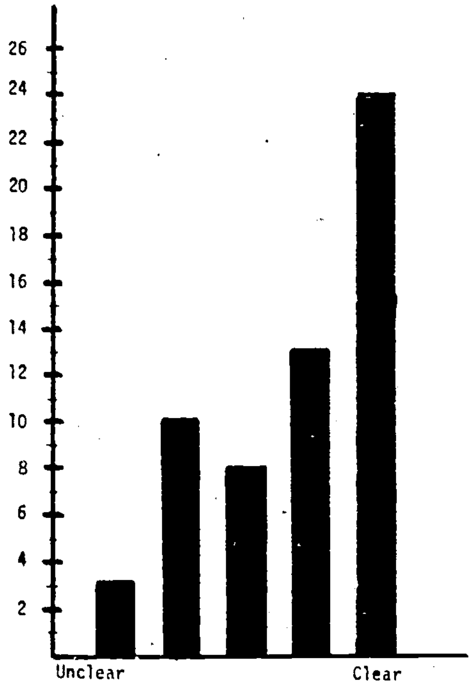
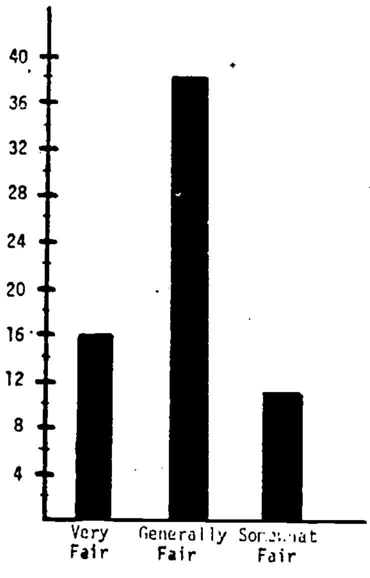


FIGURE 4



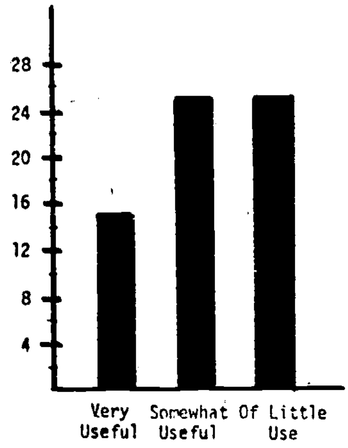

COURSE OBJECTIVES

FIGURE 5



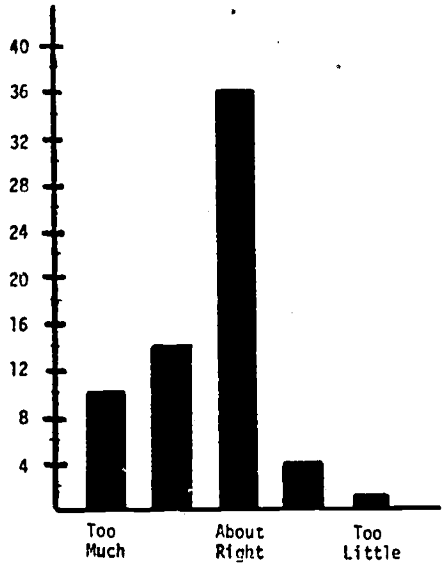

STUDY UNIT TESTS

FIGURE 6




STUDY GUIDES

FIGURE 7




WORK REQUIRED

42

FIGURE 8

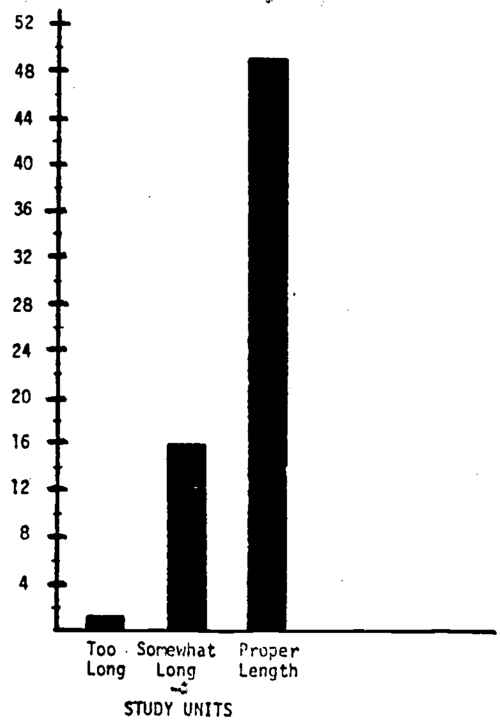
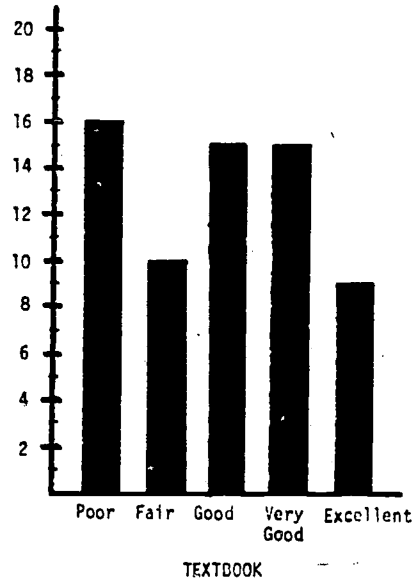



FIGURE 9



The completion pattern for the study units is given in Figure 10 along with the grades obtained by students not finishing all the units.

FIGURE 10

| UNITS COMPLETED | NUMBER OF STUDENTS | |
|---|---|---|
| 14 | 55 | |
| 13 | 4 | B, B, C, C |
| 12 | 6 | D, B, C, D, C, C |
| 11 | 1 | C |
| 10 | 1 | inc. (D) |
| 9 | 4 | F, F, W, W |
| | 71 | |

Another interesting correlation found is between the grade received in this course and the subsequent course, Chemistry 201. This data is given in Figure 11.

FIGURE 11

Correlation of 108 and subsequent 201 grades

| | Keller (1972) | | | | | | Non-Keller (1969-71) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 108 | 201 | | | | | 108 | 201 | | | | |
| | | A | B | C | D | F | | A | B | C | D | F |
| A | 18 | 11 | 6 | 1 | | | 31 | 9 | 14 | 8 | | |
| B | 12 | 1 | 1 | 9 | 1 | | 43 | - | 15 | 23 | 5 | |
| C | 8 | - | 1 | 6 | 1 | | 21 | - | 1 | 12 | 8 | 1 |
| D | 2 | - | - | 1 | 1 | | 6 | - | 1 | 2 | 2 | 1 |

The only conclusion I feel safe in drawing from these results is that the Keller students did no worse in the subsequent course than conventional lecture students. Two points of interest in addition are (1) the significantly larger number of Keller A students who continued to get A's and (2) the significantly fewer students in the Keller section who obtained B's and continued to get a B in the later course. In an attempt to follow up these results the course grade vs. final exam grade was tabulated in Figure 12. Note the significantly lower final average for the students receiving B than A grades.

FIGURE 12

Correlation of final exam average and final grade for 108 and 201

| 201 | Grade | Average Score on Final | |
|---|---|---|---|
| | A | 168/180 | 93% |
| | B | 137/180 | 76 |
| | C | 90/180 | 50 |
| 108 | | | |
| | A | 209/240 | 87 |
| | B | 145/240 | 60 |
| | C | 108/240 | 49 |
| | D | 92/240 | 38 |

Discussion.

The student reaction to the Keller pattern was sought at the end of the second course. The questions posed included (a) possible continuation of the Keller pattern in the first course and (b) extension of the method to the second course.

(a) Of the 24 respondents 13 felt the first course should be continued by the Keller method, 11 were against it.

(b) Of the 24 respondents 20 felt the second course should not be taught via the Keller pattern, 4 were in favor of such an offering.

In all, I feel these course offerings by this method were successful and, in spite of the lack of strong student support feel this option worthwhile. How to best include it as an option or to teach certain segments of a course by this method remains open in any thinking.

There are other positive features of the method, however, including the benefits obtained from approaching the teaching of the subject from a more analytical point of view. Thus the need to specify the types of knowledge or problem solving techniques expected can provide a more careful assessment of our expectations than we often are required to exact in a traditional format. Without carrying this desirability of establishing performance objectives to an extreme a recognition of the value of such a step is of definite value in my opinion.

EXPERIMENTS WITH KELLER TYPE GENERAL

CHEMISTRY COURSES AT MICHIGAN

by

R. L. Kuczkowski*, H. Brintzinger*, D. Dull* and J. Thomas*

Three different general chemistry courses have been taught using modified Keller formats at the University of Michigan. Two of the courses are now being offered for the second time using this method. This paper will primarily discuss our experiences and assessments of these two courses. The approach in this paper will be more impressionistic than analytic; we will present largely an overview of our experiences.

One of our goals in experimenting with this teaching method was to explore its potential, especially for large introductory courses at a school like Michigan. Our strategy was to first offer it to a smaller group of well qualified students (Chem. 191, Jan. 1972) in order to gain experience and insight before proceeding with a larger group of students (Chem 111, Sept. 1972) with more varied abilities. A third Keller course was also offered in the Fall of 1972. It involved ten, second semester chemistry students enrolled in the Residential College at Michigan; it will not be extensively discussed here.

Chem 191 (reported at the Mt. Holyoke Conference, J. Chem. Ed., 50, 6 (1973)) can be described as a special section of the second semester of our general chemistry course. It involved 105 volunteers who enrolled with foreknowledge of the format. About 85% of the class had obtained an A or B in the first semester course.

The Chem 191 course outline consisted of 20 units keyed to the second half of the text by Dickerson, Gray and Haight. The laboratory (8 hrs per week) was also self-paced. About 1/2 of the laboratory involved experiments on prescribed techniques. The remaining labs were divided between projects or selections from other standard experiments. The grading contract assured a B for finishing the 20 units plus 7 laboratories; an A was awarded to students obtaining about 75% on the optional final. A particularly interesting aspect of this course was that an effort was made through occasional assignments and exam questions to evoke thinking patterns from the students demanding more syntheses, correlation and non-routine applications of the principles. For example, a Grand Finale Contest was held with a prize awarded for the best essay on some natural phenomenon which imaginatively incorporated the principles developed in the course.

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Generally, a class with highly qualified students involved in a teaching experiment is "doomed to success." This class was no exception. The most objective criterion was provided by administering a final exam in common with another conventional second semester course which followed the same curriculum and text. The grade curves for the two courses (after matching students, etc.) did not indicate any dramatic differences. Although the exam scores were similar, upon analysis of the exams, there was evidence that the Keller course students performed somewhat better on the sections requiring applications of principles in new situations. Of course, it is difficult to ascertain whether this indicates that this ability was acquired during the Keller course or merely represents more intrinsic or innate differences by the students.

While the exam scores do not support any exaggerated claims of success (except insofar as they clearly indicate that the students did not learn less in the Keller section), the subjective response on student evaluation questionnaires was decisively positive. For example, 81% of them felt that they learned more (to be contrasted with the exam scores!); 75% of them would elect a self-paced organic course if it were offered. Perhaps more noteworthy is that 25% of them actually became tutors for the Chem 111 course when it was offered the next term. In summary, our experience with this particular course indicates that with a group of motivated, bright students and with effort and imagination by the faculty, a Keller course can be directed at the more creative abilities of the students and will be received enthusiastically by them.

Having acquired experience in the operation of a Keller style course, we next implemented it under less favorable conditions in Chem 111. Here, the class size was doubled to more than 225 students. Moreover, in contrast to the highly motivated students in 191, the clientele in Chem 111 was more varied in background and ability. Typically, about 80% of the class is from the School of Nursing. The students, most of whom were entering freshmen, had no alternative to enrollment in this one semester terminal course.

The course outline in the Fall of 1972 consisted of 19 units from the 4th edition of "College Chemistry" by Sienko and Plane. The grading contract guaranteed a B for completion of the units, with an optional final required for an A. The laboratory was not self-paced; it was structured in the conventional format with an assigned experiment per week. Thirty-five undergraduate tutors responded to our solicitations for 3 hours of tutor assistance per week; most of them elected to receive one credit in a chemistry teaching course for their participation.

The scores on the final exam and the number of students finishing the course are two of the more objective criteria for evaluating the course. Although no controlled comparisons were made, the exam curve based on 140 scores appeared typical and similar to that for previous Chem 111 classes. It is difficult to evaluate this information since students had nothing to lose and some may have taken the exam without much review. It again suggested, however, that the students did not learn less than with the conventional format. The high completion rate of 95% was surprising. This was higher than normal for this course and higher than is occasionally found for other Keller style courses.

The subjective student response to the course was similar to that for other Keller style courses--very favorable. This was in spite of frequently voiced complaints on their part due to poor tutoring or having to wait too long for a tutor.

Not all aspects of the course were satisfactory, however, and we introduced several changes when we repeated the course this January. First, the course was restructured into 17 units and the lab was reorganized to correlate better with the units. While this has improved the laboratory experience, nevertheless a self-paced course with a conventional weekly lab remains an awkward compromise. Secondly, the teaching fellow's role was redefined to include supervision of the tutors and the tutor room, one afternoon per week. This has very effectively decreased the need for constant supervision by the faculty. Thirdly, the tutor meetings included a more serious discussion of academic topics and course material. Fourthly, several changes were instituted in order to discourage "beating the system". For example, a student must do some homework before taking a quiz or can only fail a unit twice in one day. Finally, in response to requests by some students, we occasionally lectured on difficult material. While this has helped some students, the response in terms of numbers has been low (about 15% of the class attended).

The final evaluation of this course is still to be made; however we do not anticipate any substantial changes from the first semester in the students' performances, completion rate and attitudes. At least 90% will complete the course with a C or better.

The principal lesson from the two semesters of Chemistry 111 is that a Keller style format is manageable and well received in a large class section with a more typical clientele provided that enough tutors are available and that the mastery level is set at a B rather than at an A as prescribed by Keller. A corollary is that the majority of these freshmen who were compelled to take this course were able to respond maturely to the demands of a self-paced situation.

Based on our experiences with these courses, here are some of the advantages and disadvantages of the Keller plan in comparison to the traditional lecture format. Reservations can be expressed in regard to economy and efficiency. Although we have not dramatically increased the expense of the courses, this is largely because the tutors have not been reimbursed financially. It is also noted that the Chem 111 course has had two classrooms assigned exclusively to it for 15 hours per week which is about twice the space ordinarily utilized by the course. From a faculty viewpoint, setting up the courses has required considerably more time than normal. Conducting the course a second time certainly reduces this commitment since outlines and quizzes are in hand. However, it is clear that the faculty member cannot reduce his participation below what is normally demanded in a lecture course without the lack of leadership proving deleterious. From an academic perspective, it is not clear that our students have retained substantially more chemical knowledge from our modified Keller formats; neither do they appear to retain less.

The advantages in the Keller plan, in our experience, are to be found in the attitudes of students and staff. There are not many large lecture courses that receive the warm endorsement of upwards of 80% of our students. Without analyzing the many advantages cited by students, it can be simply summarized that the students described the learning experience as more pleasant and rewarding. This positivism is difficult to ignore when one assesses his own benefits as a faculty person, teaching fellow or tutor in the course. For example, 4 of the 5 teaching fellows and 15 of the 36 tutors in the first semester of Chem 111 volunteered again for the second semester rerun.

Our present assessment is that the balance between advantages and disadvantages will result in a compromise with several introductory courses to be taught by this format in a given year at Michigan depending upon staff and facilities. Both 191 and 111 will probably be taught this way the next two years; three faculty, not involved in the original courses, have already spoken for these assignments. Because of the organizational and space requirements, we do not anticipate any expansion of the Keller format into our larger introductory courses (1000-1500 students). Perhaps in the future, one lecture section of these courses (300 students) will be organized by this format and will be made optional to the students. This would provide a learning alternative for both student and staff and contribute to the diversity of experiences that should be available at a large university.

# A SELF-PACED COURSE IN ORGANIC CHEMISTRY

by

Homer A. Smith, Jr.*

Self-paced methods of instruction, widely used for several years in areas such as psychology, physics, and engineering (1-4), have recently begun to have an impact upon the teaching of chemistry (5-8). Most early developments have been at the general chemistry level and few, if any, self-paced offerings have been reported in more advanced courses such as organic chemistry. A one-semester self-paced organic course entitled "An Introduction to Structure, Bonding, and Mechanism" (Chemistry 5.41) has been offered by Vournakis (9) at MIT.

During the 1972-73 academic year a two-semester self-paced course in organic chemistry (Chemistry 201-202) was given at Hampden-Sydney College, a small four-year liberal arts college. The course replaced a conventional lecture course previously offered by the same instructor using the same textbook and carried a credit of three hours per semester, the associated laboratory being offered as a separate course. The majority of the 48 initial enrollees were premedical and predental students, and most of the remainder were science majors. The course materials were keyed to the text by Hendrickson, Cram, and Hammond (10), and the students were also required to obtain a solutions manual (11), a paperbound problem book (12), and a set of molecular models. The material in this text (10) is well suited to self-study in that the organization is excellent and the presentation is logical and readable. However, certain characteristics of this text require careful attention in the preparation of study guides for the course units. First, the text is very compactly written and additional discussion was required in many study guides. More importantly, it contains very few elementary practice problems; many such problems were devised for the study guides and others were assigned in the problem book (12).

The course material for each semester was organized into 20 units. The topics of the first semester units are summarized in Table 1 and those

Table 1. First Semester Topics

| Units | Topics |
|---|---|
| 1-6 | Structure, nomenclature, functional groups |
| 7-8 | Resonance, aromaticity |
| 9-10 | Spectroscopy |
| 11-13 | Stereoisomerism, conformational analysis |
| 14 | Review |
| 15-16 | Acid-base theory |
| 17 | Reaction classification, transition state theory |
| 18-19 | Nucleophilic substitution |
| 20 | Review |

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of the second semester units in Table 2. Semester grades were determined solely on the basis of number of units completed according to the scale in Table 3. Students who did not complete all 20 units first semester were

Table 2. Second Semester Topics

| Units | Topics |
|---|---|
| 21-22 | SN reactions in synthesis |
| 23-24 | Nucleophilic addition: synthesis and mechanisms |
| 25-26 | SN reactions at unsaturated carbon |
| 27 | Monosaccharides |
| 28 | Amino acids, proteins |
| 29-30 | Electrophilic aromatic substitution |
| 31 | Elimination |
| 32 | Mechanisms review |
| 33 | Synthesis review |
| 34-40 | Special topics |

Table 3. First Semester Grade Distribution

| Units Completed | Grade | Percentage of Class |
|---|---|---|
| 20 | A | 61 |
| 18 | B+ | 17 |
| 17 | B | 0 |
| 15 | C+ | 7 |
| 14 | C | 7 |
| 13 | D+ | 0 |
| 12 | D | 4 |
| 0-11 | F | 4 |

required to begin with the next unit in sequence for their second semester work; their second semester grade was determined by the number of units completed from the second semester starting point. This policy was made necessary by the sequential nature of the subject matter. In order that students who did not complete all 40 units would still cover the basic core of organic chemistry, seven units on special topics were placed last in sequence (see Table 2). Actually twelve special topics units were offered and students were given a free choice among them after completion of unit 33.

Class progress was rapid and steady during first semester, and procrastination was a serious problem with only a small minority of students. The class as a whole proceeded at an average rate greater than the "A rate" (the uniform rate which would result in the completion of the twentieth unit on the last day of the semester) for about three weeks and then remained only slightly below that rate for the remainder of the semester. The first semester grade distribution is shown in the last column of Table 3. The major stimulus for steady progress seemed to be the graph of progress which each student kept for himself on a form provided by the instructor. Average progress was slow during the first month of second semester, primarily because of the failure of about one-fourth of the class to begin work, including most of those who had made C or D grades first semester. After written warnings were sent to students with unsatisfactory progress, average class progress steadily improved and attained a rate near that of the first semester within another month. Incidentally, we have observed the same slow progress at the beginning of the second semester segment of our self-paced general chemistry course, and this may be a general phenomenon in continuing courses.

The course met three times weekly for 110-minute periods. Thirty-minute written tests on each unit were administered upon request from individual students only during class meetings with a limitation of two tests on a given unit in a given class period. Tests were checked by six student tutors, except for review units 14, 20, and 32, which were checked by the instructor. One error (out of about ten questions) was permitted on review unit tests but essentially no errors on other tests. However, students were given an opportunity to correct arithmetic and other minor errors and to expand verbally on incomplete answers. A student not exhibiting the required mastery on a unit test was required to take other forms of the test until mastery was demonstrated. Four or five forms of the unit test were generally sufficient to accommodate all students. The easiest unit first semester required an average of 1.20 tests per student, the most difficult one an average of 2.25 tests, and the average unit 1.72 tests. The quotient of total tests taken divided by total units completed ranged from 2.8 for the "least efficient" student to 1.1 for the "most efficient" one.

A novel feature of the course which worked out well was the use of take-home open book tests for unit 32. Each test consisted of three reactions for which the mechanisms were to be deduced. The problems selected were challenging ones involving extension of basic mechanisms given in the text or combinations of principles from two or more standard mechanisms. The problems served as an effective device to require review of basic mechanisms and permitted an in-depth testing of mechanistic understanding not possible on 30-minute, closed book tests. Students were not permitted to obtain help from others, which probably limits the use of take-home tests to institutions with an effective honor system.

Tutors were chosen from students who had done well in the previous year's lecture course using the same text. Each tutor was assigned eight or nine students, which appears to be the maximum number which can be effectively handled in this kind of course. Tutors received one credit hour but no remuneration except for one tutor who also served as file clerk. The tutors exhibited skill and professionalism in checking unit tests and assisting students and also appeared to increase substantially their personal knowledge of organic chemistry.

Student acceptance of the course has been gratifying, with 94% of those responding to an end-of-semester questionnaire indicating a preference for this course over a conventional one. Of greater importance has been our finding that our students, drawn from a student body with CEEB scores only slightly above average, are capable of learning organic chemistry from a rigorous textbook on their own accurately and thoroughly. The classroom role of the instructor has been a very satisfying one. Rather than being separated from his students by a wall of words as in a lecture course, he has been free to devote most of his class time to assisting students on a one-to-one basis. To an experienced teacher who has been accustomed to the "show me" and "repeat that" type of question, the questions asked by self-paced students have come as a refreshing change. It is a pleasant revelation to the instructor to find that the questioner has invariably already studied the material well and has an intelligent, appropriate question and, more importantly, that he is ready to benefit from the answer. Our observations of ordinary students pacing their work intelligently, mastering difficult material thoroughly on their own, and asking worthwhile questions is sufficient, in our opinion, to dispel the misgivings of others (13, 14) concerning the intangible factors that may be lost in a non-lecture format.

One problem in our course seemed to be the fragmentation of learning, based upon occasional instances in which students could not apply material "mastered" on a previous unit in a new one. Of course, this is a problem in a lecture course as well, and it may be that the instructor is simply more aware of it owing to better contact with students in a self-paced format. In practice, this better contact with students translates into knowledge of specific principles and facts that are not being retained sufficiently well and suggests its own remedy in indicating the specific matters which require reiteration. Thus in our revision of the course materials, we plan to incorporate overlap of selected material among units and to employ more review units.

## Acknowledgment

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# A CRITICAL ANALYSIS OF A TRUE KELLER COURSE IN PHYSICAL CHEMISTRY

by

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There are many aspects involved in discussing and evaluating any system of instruction. Instructional sequences involve so many variables and self-fulfilling results that an adequate analysis is almost impossible. In the end subjective opinions must carry the most weight. We shall attempt in this paper to report on the results of a Keller Course in Physical Chemistry with emphasis on the student response and the instructor-student interaction. Outside of comments based on personal experience, no accurate statements can be made concerning the grades obtained by the students. In addition we shall comment briefly on the cost aspects of this course, how this course differs from lower level courses.

To begin, the class consisted of about 20 juniors and seniors, mostly chemical engineers, randomly selected from those taking the second semester of physical chemistry during the Spring of 1972. The course was taught by a true Keller method plan by which we mean a) the course is divided up into about 20 units, b) study guides are prepared for each unit containing instructional objectives, study questions, sample problems and other information which the student must know in order to pass each unit, c) it is self-paced but each unit must be mastered to "perfection" (90% in our case) before the student can proceed to the next unit, d) there are a few lectures or demonstrations used for enlightenment but not required and not for the purpose of presenting remedial material, e) proctors are present in a ratio of about 1 to 10 to grade exams and discuss questions, f) a final exam was given (this is optional), g) grades are determined primarily by amount of material completed and not on the amount of time it takes to complete the course. These represent a paraphrase of comments by Fred Keller (1) at the Rice University Conference last March. Any significant tampering with these leads to side effects which weaken the impact of this entire learning environment, and introduce aspects which limit the reinforcements built into this system. The objectives and means for obtaining a certain grade are clearly stated at the outset and it is up to the student to meet these criteria.

The course content was as outlined in Table I. These units were arranged in careful order for shaping behavior. Since most students were chemical engineers the kinetics material was put first so they would find the first few units easy and thus help to eliminate procrastination. Also the units on quantum chemistry and spectroscopy constantly used material

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**Table I**

Organization of Units

| | |
|---|---|
| Units 1, 2, 3 | - Chemical Kinetics |
| Unit 4 | - Transport Properties |
| Units 5, 6, 7 | - Principles of Quantum Chemistry |
| Units 8, 9, 10 | - Applications of Quantum Chemistry |
| Units 11, 12, 13 | - Chemical Spectroscopy |
| Units 14, 15 | - Statistical Mechanics |
| Unit 16 | - Molecular Symmetry |
| Units 17, 18 | - Other methods of determining Molecular Structure |
| Units 19, 20 | - Optional Special Units |

from earlier units so the students were forced to review and keep the majority of the course fresh in their mind. The specific subject matter and the actual objectives used in the course are based on the content it had when this author taught the same course in the "pre-Keller" days. The first thirteen units represent what is considered minimally essential in a second semester physical chemistry course. Many of the study guides contained much additional material which went beyond that represented by the text, "Physical Chemistry" by Daniels and Alberty. The actual level was similar to that of Moore's text. This is particularly true of the Quantum Mechanics, spectroscopy, and statistical mechanics units where the study guides were often 4-8 pages in length. Typical study guides are about two pages. Additional references were quoted but were not required reading. The two extra or "enrichment" units for the faster students covered topics of interest to each individual but had to have strong physical chemical content. Most involved outside reading.

There were four to six equivalent forms of an exam prepared for each unit. These exams should only take a student about 15 minutes to complete. These were randomly given to students with no one ever taking the same exam twice. A graduate student and the senior author served as proctors, with a total of nine hours per week available as "test" periods, including the normal three hour class period. At least one of us, if not both, was present at each of these periods.

Some elementary statistics may be of interest here. On all but two units, most students passed a unit on the first try. On one unit, however, one student required five tries before he passed. Over all eighteen units there were 229 successful first tries, 70 successful second tries, 22 successful third tries, 5 successful fourth tries, and one successful fifth try. We gave special attention to those requiring more than two tries. Often these people were not studying the material properly. With these students we went over their typical homework problems carefully. In all cases the exams were graded with the student present and he was told the correct answer. If he misunderstood the question or if it was ambiguously worded he was given an opportunity to defend his answer. In every case he should have understood the correct answer before he left the room.

The student's progress was kept in a file which was always available at our proctoring sessions. Upon successful completion of a unit, this was entered in the student's file and a gold star was placed on a chart on the bulletin board devoted to this course.

It is important to understand the difference between this course and a freshman course. First of all, experienced tutors are needed. They should be at the very least seniors, preferably graduate students since the subject matter often involves discussions on a broad range of material, much of which cannot be outlined easily on an answer sheet for each exam. In addition the subject matter is such that complicated questions far afield of the actual course content often arise which require quantitative answers. Both times this course has been taught excellent graduate students have been involved as tutors. These people greatly simplified the work of the instructor. Also, since these graduate students are younger and also students there seems to be more empathy and understanding between proctor and student. In addition, grading an exam, especially if incorrect, involves a sizeable amount of time. Typically an exam requires 3-4 minutes to grade but it can often take 15 minutes to explain and discuss all of the features. This at times can put pressure on proctors even if they are in the ratio of one per eight students. Students become very upset if they must wait over 5 minutes to have an exam graded and with good reason.

The grading schedule is given in Table II. The average of the class progress is shown in Figure 1. The final grade distribution was 14-A's, 3-B's, and 2-C's(2). There is an excellent correlation between the number of units completed and the final grade in the course. There were only two minor exceptions involving borderline cases. There was essentially no correlation between the final exam grade (based on a 90, 80, 70, 60% scale) and their grade in the course. The reason was obvious. Students only worked hard enough on the final to maintain their letter grade. Most students barely studied for the final. However, based on teaching similar courses in the past it is our opinion that the students understood the material better than when taught by the traditional lecture method. On the final exam, for example, the answers which were given were very good with none of the nonsense one often sees on finals. They were not allowed to ignore nor mislearn some of the basic aspects of the course. Moreover the final exam average was about 65%, not bad for this course.

Table II

Grading Scheme

Units completed at end of course =

Units completed x 25 =

Final Exam Grade (out of 150) =

Score for the course =

| | Points |
|---|---|
| A - 90 - 100 % | 540-600 |
| B - 80 - 89.99 % | 480-539 |
| C - 70 - 79.99 % | 420-479 |
| D - 60 - 69.99 % | 360-419 |

Figure 1

CUMULATIVE RECORD OF PROGRESS IN PHYSICAL CHEMISTRY 104

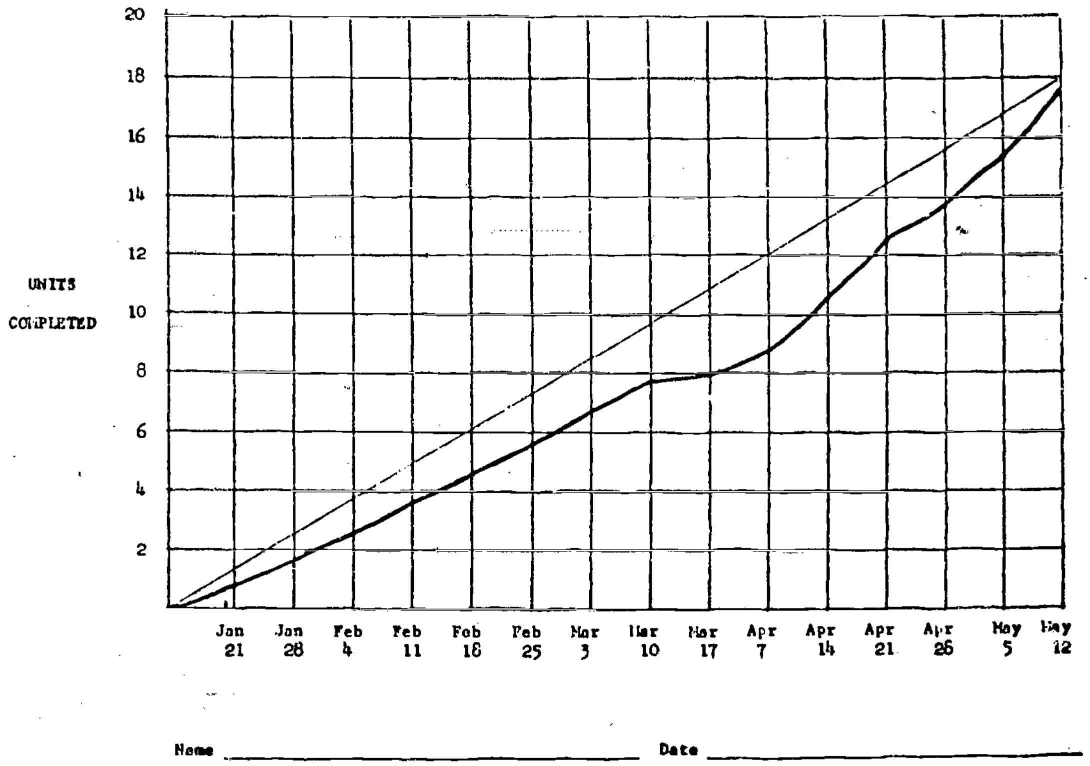



Figure 1. Progress chart of the class average during the semester versus a uniform line of progress.

In this paper we shall concentrate on the unique features of the Keller plan and quote student and instructor reactions. A student evaluation form was completed by each student at the end of the course in a confidential manner. The unusual rapport this course fostered with the students encourages us to think that these results are completely honest. The student comments can be summarized as follows: They spent a lot of time on the course but feel they learned more and enjoyed it more. They became less anxious about taking tests, received more attention from the instructors (3), and improved their study habits. The students ranked the features of the course they enjoyed most and those features which helped them learn more as summarized in Table III. The aspect the students liked most was the self-pacing and frequent tests; the freedom they had to go on their own. This, however, caused a few people the most problems since they had to overcome poor study habits and learn to motivate and pace themselves. (4) For some this problem grew worse toward the end of the semester. Problems with the textbook explanations on certain points irritated the students despite the fact that proctors were available to discuss these points and the study guides elaborated upon the weaker areas.

Table III

Ranking of Various Keller Course Features

by Students

| As regards enjoyment of course | |
|---|---|
| self-pacing | 2.3/10 |
| interaction with instructor | 2.7/10 |
| unit study guides | 3.1/10 |
| interaction with proctor | 3.8/10 |
| required mastery | 3.8/10 |
| frequent tests | 4.1/10 |
| problem solutions available | 5.0/10 |

| As regards learning in course | |
|---|---|
| interaction with instructor | 2.7/10 |
| self-pacing | 2.8/10 |
| frequent tests | 3.0/10 |
| required mastery | 3.4/10 |
| interaction with proctor | 3.9/10 |
| problem solutions available | 4.4/10 |
| lectures | 6.5/10 |

At least one student who completed the course did not like a self-paced course. He discussed his objections with us many times during the semester. He said he had always had lecture courses and felt more at ease in them. In his opinion it was easier to learn from a lecture. The majority of the students (11 out of 18 replies) said they would like more courses of this type, four more said they would search out such courses while only three said they would not object but would attend such a course with reluctance.

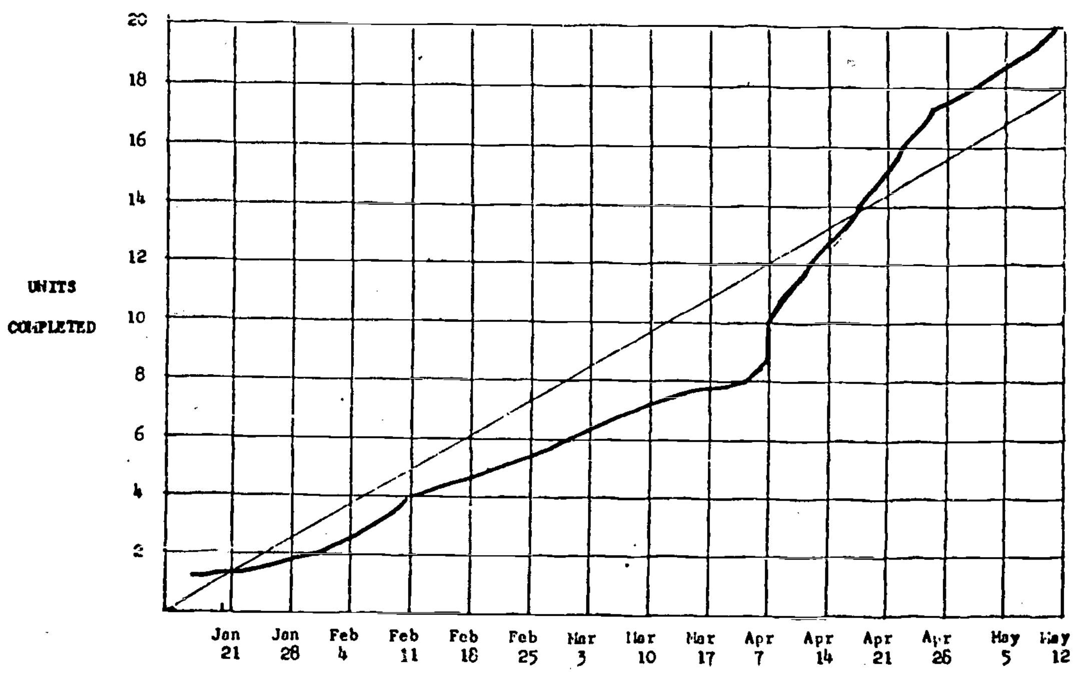
From the instructor's point of view, teaching this course the first time requires an extraordinary amount of time preparing the material. Organizing one Keller course is about the same as teaching three or four lecture courses. However, once the material is prepared teaching this course was a pleasure. The amount of interaction with the students is very great and most of ones time is spent teaching, i.e. discussing students problems, working through their difficulties, not repeating a textbook (written or unwritten) or putting on a show for its own sake. The student comes to the instructor only when he has made an initial try at understanding the material, so that a high level discussion can occur. In this author's experience the amount of discussion which goes on in Keller courses concerning both required and ancillary material far exceeds that which occurs in the normal lecture course. In this regard and in many others, one must be very careful in making sweeping generalizations since much depends on the personality of the instructors and proctors. It should be less variable for Keller courses since all basic material is printed than for lecture courses where the entire flavor of a course is entirely dependent on the professor in charge and his classroom techniques. To put the time involved in this course in proper perspective it should be said that now that the course is being taught a second time the amount of time spent by the instructor is roughly the same as that of a lecture course.

One of the main enjoyments of the Keller course is one's involvement with the students. The atmosphere in a Keller course is something everyone, especially professors, should experience. It is very open with none of the boredom or anxiety one usually observes. And remember that in a Keller course some students are almost always taking an exam. They are even able to joke about failing, or take a ribbing from a friend about not passing a third exam on a unit. With some students this attitude takes a long time to achieve. One student could not believe we would grade an exam while he watched. He suspected all professors were trying to cheat him out of his grade. At the start of the semester he became rather angry when he had to retake an exam. There were some very heated exchanges between the proctor and him. The instructor stayed out of this unless they agreed to an impartial arbitrator. As the semester progressed this student's attitude changed gradually and at the end of the semester he was able to feel at ease taking exams, even joking about his previous bitter reactions. This case was extreme and handled excellently by a very compassionate and open proctor, but it does indicate that the benefits of a Keller course extend far beyond the confines of this one course. The improved study habits, the better understanding of the teacher's role, and the ability to motivate one's self should carry over into other courses. All students should take at least one Keller course to be exposed to this type of background.

Not all students go through this course at the same rate or in the same way. Consider in Figures 2 and 3 the progress charts of two students, both of whom got A grades in the course. The first student (Fig. 2) proceeded in

Figure 2

CUMULATIVE RECORD OF PROGRESS IN PHYSICAL CHEMISTRY 104




Name ______________________ Date ______________________

Figure 2. One A Student's Progress.

a more or less uniform manner and completed the two enrichment units. The other student (Fig. 3) moved through the first part of the course very rapidly (forcing the instructor to keep ahead of him). Then he took time off to work on projects in other courses for several weeks. Later he returned to finish off the rest of the required units. He completed the work necessary

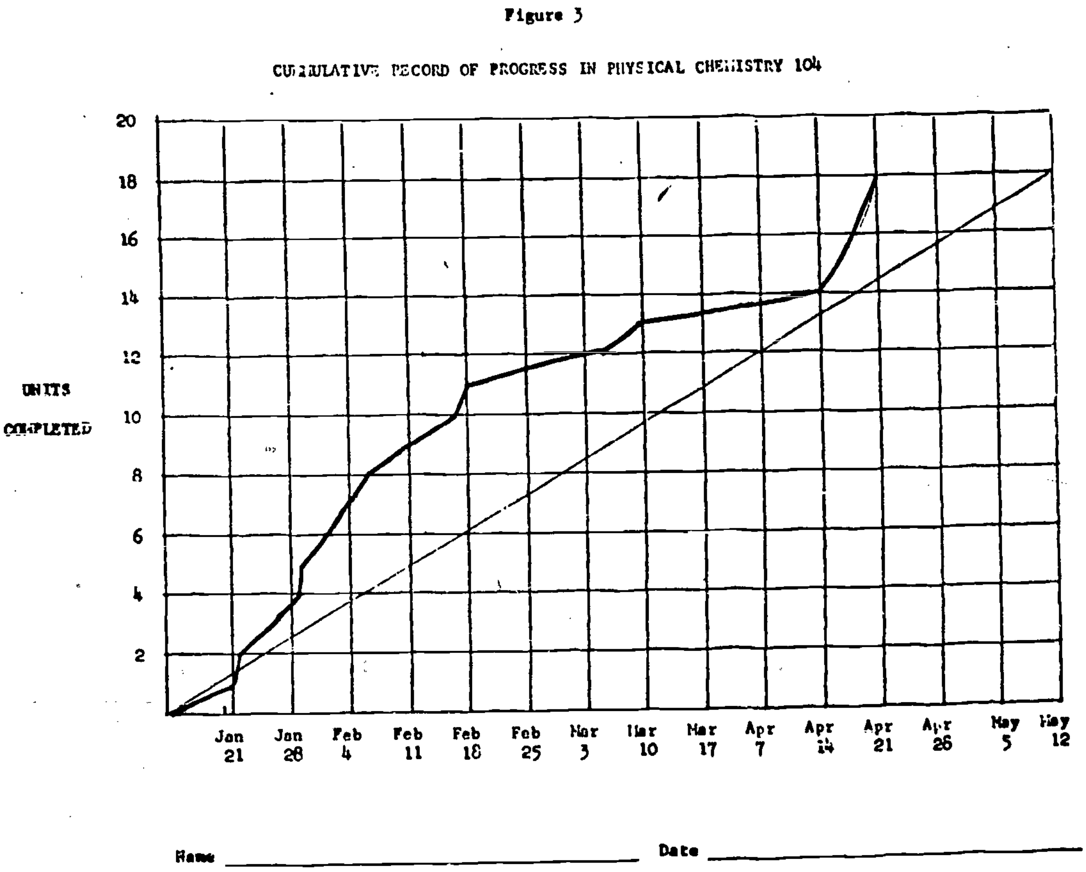



Figure 3. A Second A Student's Progress.

for an A grade by writing a very good final exam. On the other hand we see in Figure 4 a person who got the lowest grade in the course, a C. The initial weeks are marked by procrastination, not taking exams or taking them without studying. He found it very hard to self-pace and motivate himself. Nevertheless by hard work he did bring his grade up to the C level. Procrastination is always a problem and there is no simple answer. Students who have taken another PSI course tend to have extinguished this behavior.(5)

Figure 4

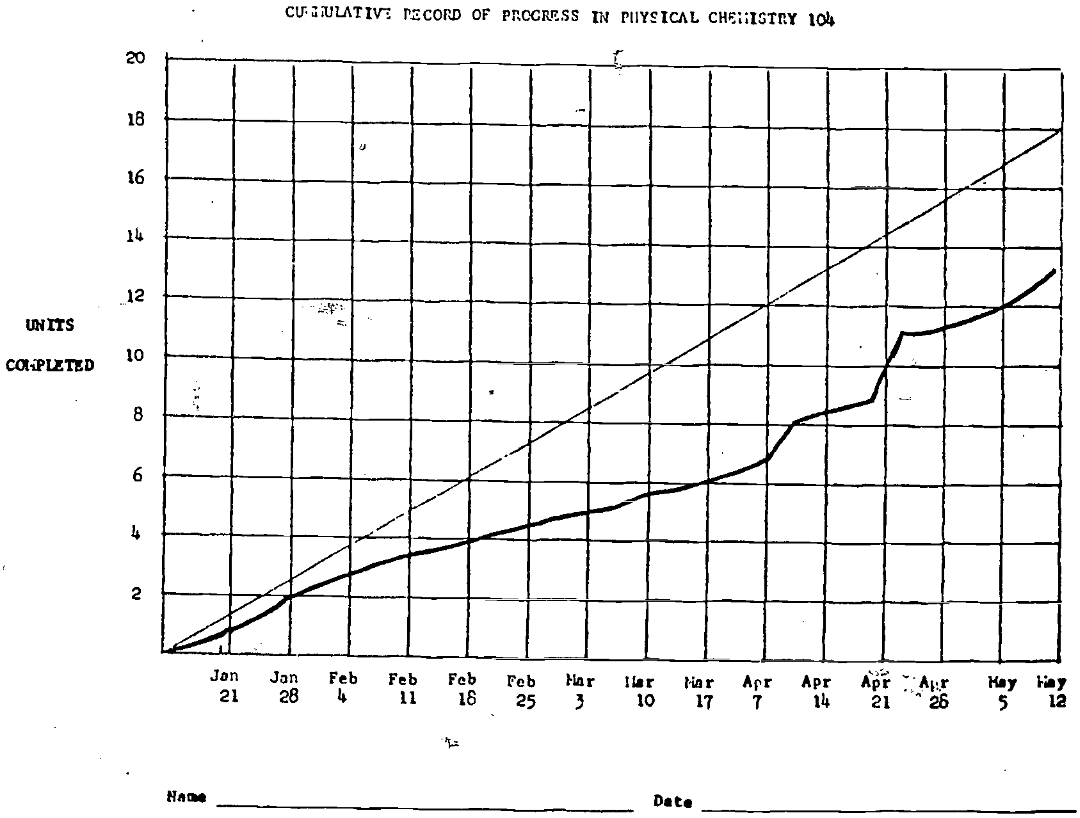



Figure 4. A C Student's Progress.

Since this course allows students to proceed at their own pace it is an ideal system of instruction for a very heterogeneous class. Currently we have a student in class who has had some of the material in a previous lower level course at another university. He had been able to do 75% of the work in about half of the semester. On the other hand students who are not familiar with the material often do not finish the course or must work harder to complete the course. This is especially true concerning chemical engineers in the quantum mechanics sections. Thus each student really takes a different course. Each gets troubled by different materials, each takes a different sequence of exams, all dependent on his background, study habits, and abilities. This flexibility is the beauty of this system. It could even be extended so the last half of the course is different for each student depending on his interests and background.

To properly judge a Keller course it must be taught more than once. The first time one is so involved with the mechanics of the course he does not have time to appreciate its fine points. This course is being taught for the second time this semester and it is a very enjoyable experience. At times it seems as though the instructor is not needed once the course has been properly organized and all materials are available.

It is important to attempt to summarize the merits and disadvantages of the Keller Plan in Physical Chemistry. First, the advantages are better trained students, especially in the fundamentals; increased and improved student-teacher relationships; students who can set their own pace through the course, are responsible for their fate; honest grading standards, and last but not least, more interested students. The disadvantages are first of all the work involved in setting up the course for the first time and the relatively high cost of this type of instruction. It is very important to have about one proctor for every ten students. With the instructor plus one proctor no more than twenty-two or so students can be handled. With graduate students becoming more scarce this could cause problems. Another serious problem in our case and in most schools is space. Ideally we need one room devoted to the course. Now we use three different rooms at various times of the week. Other minor problems with these courses are the huge amount of paper work involved. However, with the right organization this could be automated with the computer keeping track of student progress and also generating random exams. Nevertheless there would still be exams to file. It is very important to keep the grading of the exams personal and not computerized. In this way all types of exam questions can be used and the student can make a wide variety of responses. This is also the only way that the true breadth of the student's understanding can be explored.

Despite the satisfaction with the course as originally taught some modifications are being explored.(6) This semester a group final exam will be given to these students and those in a standard lecture course exposed to the same material in the hope of obtaining some information on their relative standings. However, more valid results could be obtained by comparing students who had introductory material (possibly first semester Physical Chemistry) by the Keller method and then went on to another course which demanded the application of the previously learned principles. Very often our students do poorly because they have not mastered the fundamentals before they are asked to apply them.

In summary the Keller Plan is an ideal way to teach Physical Chemistry if the university is willing to support this project. The rewards and results are great. Given such support this instructor would teach in no other way.

## Acknowledgements

The author wishes to thank the Chemistry Department and the College of Chemistry and Physics at Louisiana State University in Baton Rouge for their support. The very able proctors assigned to this course were Sr. Roberta Hollier (1972) and Larry David (1973). These proctors helped make teaching this course a real pleasure.

References

(1) F. S. Keller, Proc. Keller Method Workshop Conf., Rice University, Houston, Texas, March 18, 1972, A. J. Dessler, ed.

(2) Three additional students dropped the course within the first four weeks. The major reasons were that they fell behind at the beginning and by the time they realized it they felt they could not catch up.

(3) One student complained however, that he regretted not being able to get help from his proctor when he studied late at night.

(4) Students who had taken a previous Keller type course even if it was in another department had fewer problems self-pacing themselves.

(5) During this current semester several letters were sent to the lagging students giving them a status of the position in the course and indicating that we missed them in class.

(6) Some interesting ideas for modifying the relative importance of final exams, for discouraging procrastination, and for further rewarding the faster students are contained in an excellent new book, "Learning is Getting Easier" by S. R. Wilson and D. T. Tost; (Individual Learning Systems, 1972).

INCLUSION OF LABORATORY IN KELLER PLAN COURSES

by

Erich C. Blossey* and John S. Ross**

We used the Keller Method in two different courses at a time (1971) wher there was little information available concerning courses which included laboratory. The basic problem as we saw it was the institution of a self-paced course and operation of a laboratory which generally demands rigid time constraints.

The Physics-Chemistry course has operated on the Keller format for the last two years at Rollins. It is an introductory course for Freshmen science and math majors with a co-requisite of calculus. The usual enrollment ranges from 90 to 160 students and is staffed with three instructors, 6 to 8 tutors, a graduate lab assistant, and 4 lab assistants. The topics included in the two terms of the course are shown in Tables 1 and 2.

Table 1

Physics - Chemistry

Fall Term

| Unit Number | | Title |
|---|---|---|
| 0 | | Slide Rule and Scientific Notation |
| 1 | | Particles of Nature |
| 2 | | Stoichiometry |
| 3 | | Space, Time, and Motion |
| 4 | | Accelerated Motions |
| 5 | | The Various Forces of Nature |
| 6 | | Force, Inertia, and Motion |
| 7 | | Using Newton's Laws |
| 8 | | Universal Gravitation |
| 9 | | Conservation Laws |
| 10 | | Review of Mechanics |
| 11 | | Gas Laws |
| 12 | | Kinetic Molecular Theory |
| 13 | | Phase Changes |
| 14 | optional | Relativity |
| 15 | optional | Thermodynamics |

Table 2

Physics - Chemistry

Spring Term

| Unit Number | Title |
|---|---|
| 1 | Electrical Forces and Fields |
| 2 | Electrical Work |
| 3 | Electrical Energy |
| 4 | Atomic Particles |
| 5 | Nature of Light |
| 6 | Wave-Particle Duality |
| 7 | Bohr Model of the Atom |
| 8 | Atomic Spectroscopy |
| 9 | Introduction to Quantum Mechanics |
| 10 | Electron Configurations of Many Electron Systems |
| 11 | Chemical Periodicity |
| 12 | Periodic Table and Chemical Reactivity |

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The stated evaluation procedures of student work is given in Tables 3 and 4. In Table 3 the laboratory work of the course was included as an integral part of each study unit. Before successfully passing a unit, the student was required to have completed the laboratory exercise included in the study guide. Table 4 shows the evaluation methods used when lab work was separated into individual units apart from the study guides.

Table 3

Evaluation of Units with Laboratory

| Grade Range | Points |
|---|---|
| A | 450 - 500 |
| B | 400 - 449 |
| C | 350 - 399 |
| D | 300 - 349 |

| | |
|---|---|
| Passed Units | = 25 points |
| Final Examination | = 150 points |
| 14 Units | = 350 points |
| Total Points Possible | = 500 points |

Table 4

Evaluation of Separate Study Units and Laboratory

| Units | Number of Units | Points |
|---|---|---|
| Electronic Lab | 5 | 125 |
| Qualitative Analysis Lab | 5 | 125 |
| Unknown Determination | 2 | 30 |
| Study Units | 12 | 300 |
| Final Exam | | 150 |
| | TOTAL | 750 |

| Grade Range | Points |
|---|---|
| A | 700 |
| B | 625 |
| C | 550 |
| D | 475 |

The second course taught under the Keller Plan was Biochemistry. This particular course enrolled 6 seniors and 3 graduate students. Table 5 indicates the unit topics for the one term course. Grade evaluation was based

Table 5

Biochemistry 431

| Unit Number | Title |
|---|---|
| 1 | Acids, Bases, and Buffers |
| 2 | Amino Acids |
| 3 | Peptides and Polypeptides |
| 4 | Proteins |
| 5 | Enzyme Kinetics |
| 6 | Enzymes and Coenzymes |
| 7 | Thermodynamics and Biochemicals |
| 8 | Carbohydrate Structure |
| 9 | General Carbohydrate Metabolism |
| 10 | Citric Acid Cycle |
| 11 | Lipid Structure |
| 12 | Lipid Metabolism and Biosynthesis |
| 13 | Nucleic Acid Structure |
| 14 | Protein and Amino Acid Biosynthesis |

on the scheme shown in Table 3 since laboratory exercises were included in the study guides. The staff consisted of one faculty member (E.C.B.) who served as coordinator, tutor, and lab instructor.

Two basic plans have been used with respect to the relationship of laboratory exercises and study guides. The first approach taken was to include directions for lab work into the study guides. Students were assigned lab times and generally completed the exercises within the allotted time <u>if</u> they were progressing at the normal pace. The advantage of this approach is the direct, immediate relationship between study material and the laboratory experience. Although most students appreciated our efforts to integrate theory and practice, evaluations of the course indicated some problems with this method (see Table 6).

Table 6

Course Evaluation

1. Were the objectives of the course clearly defined at the start?

| Unclear | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Clear | |
|---|---|---|---|---|---|---|---|---|---|
| % response | 3 | 1 | 6 | 10 | 21 | 21 | 38 | | 5.6 average |

2. How would you rate the amount of total material required in this term of the course?

| Too little | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Too Much | |
|---|---|---|---|---|---|---|---|---|---|
| % response | 0 | 1 | 1 | 14 | 36 | 33 | 15 | | 5.4 average |

3. How would you rate the amount of laboratory work required this term?

| Too little | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Too Much | |
|---|---|---|---|---|---|---|---|---|---|
| % response | 1 | 1 | 5 | 51 | 25 | 12 | 6 | | 4.6 average |

4. If you had to do the same amount of reading problems and laboratory work, but had the option of taking fewer tests, each over a larger study unit, or more tests over smaller units which would you prefer?

28% prefer larger units - fewer tests
62% prefer smaller units - more tests

5. Number of units completed:

| Units: | 4-5 | 6-7 | 8-9 | 10-11 | 12-13 | 14-15 |
|---|---|---|---|---|---|---|
| % | 17 | 6 | 12 | 14 | 36 | 16 |

6. Averaged over the entire term, how many hours per week did you spend in preparation for this course, including laboratory time?

| Hours: | 0-3 | 4-6 | 7-9 | 10-12 | >12 |
|---|---|---|---|---|---|
| % | 4 | 16 | 42 | 30 | 8 |

7. Did having the laboratory experiments tied in with the reading material of the unit slow your progress?

| Considerably | 1 | 2 | 3 | 4 | 5 | 6 | 7 | No Effect | |
|---|---|---|---|---|---|---|---|---|---|
| % response | 13 | 20 | 15 | 21 | 14 | 10 | 8 | | 3.7 average |

8. How would you compare self-paced instruction to the more conventional lecture-discussion method of learning.

| Worse | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Much Better | |
|---|---|---|---|---|---|---|---|---|---|
| % response | 5 | 6 | 10 | 12 | 14 | 17 | 37 | | 5.2 average |

9. Averages of Various Educational Devices

| | Average Response (1-7) |
|---|---|
| (a) Programmed material | 4.8 |
| (b) Study room | 5.7 |
| (c) Film Loops | 3.4 |
| (d) Audio cassettes | 4.4 |

The fast-paced students, in particular, felt a strong constraint of the laboratory work holding back their progress. We were gratified with the overall response to the course, the motivation demonstrated by most students, and the independent study habits developed by the students.

In order to circumvent the laboratory problem, a second approach was tried in which separate lab units were prepared. Points were assigned (see Table 4) to both study guide and lab units. Some form of quiz was administered at the conclusion of the laboratory exercise, unknowns in the case of qualitative analysis and brief quizzes testing technique and theory of the electronic units. The student response to this method was much improved over the first method. However, students felt there was some disadvantage to having laboratory work independent from the study guides. This was particularly true of those students that were behind in the study units but attempting to keep up with the normal pace of the lab units. In other words, these students did not have the theoretical background to do the practical application.

The major difficulties mentioned with the second approach were: the amount of different equipment needed to stock the labs, space requirements for the various experimental stations, and the number of staff that had to be familiar with each experiment. To ease these problems, a two-track system was set up wherein one-half of the class started on the electronic section and the other half began qualitative analysis. Students switched sections upon completion of their initially assigned section.

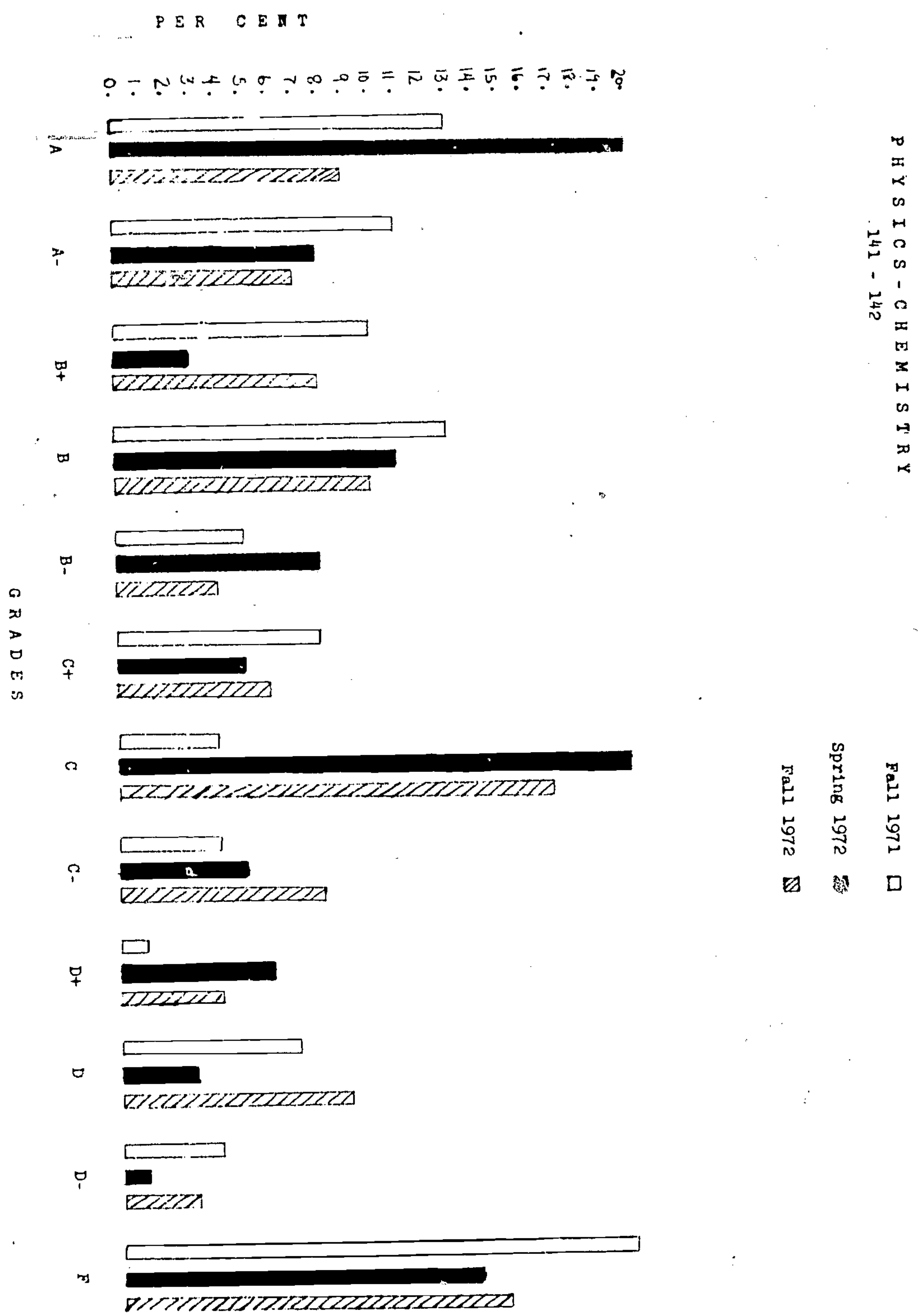
From our observations of the two methods dealing with lab in Keller courses, we recommend that separate lab units be used and that they be closely synchronized with the study units.

Other observations include grade distributions and the fate of "Keller" students in advanced, conventional courses. Our grade distribution for Physics-Chemistry (see Table 7) over three terms is quite similar to the distribution obtained in previous courses having the same content but taught by conventional methods. We have consistently found high proportions of A-B and D-F grades with concommitant decreased C populations for a number of years, Table 7.

As to the fate of "Keller" students in conventional courses, we have only limited data on our 1971-72 students in two advanced science courses. Twenty-one students from Physics-Chemistry were enrolled this year in organic chemistry and atomic physics. The net grade change of these students was a loss of 2 grade points from their last term grades in Physics-Chemistry (based on a 12 point system). The greatest change was noted in B students, dropping an average of 4 points. The A's and C's dropped only slightly as might be anticipated with advanced courses. The suspicion was that B students were rather marginal in their marks. These students could complete all of the Keller units and perform poorly on the final comprehensive exam and yet achieve a grade of B. To improve the retention of knowledge of this type of student, it would be useful to place more review units throughout the course.

Our experience with the Keller Method has been very gratifying in view of student response. It probably is best summarized by one student's comment, "...The most exciting educational experience of my whole academic career".

Table 7 - Grade Distribution



THE ROLE OF PERFORMANCE OBJECTIVES IN COURSE DESIGN

by

Jay A. Young* and Brenda W. Hill**

To teach effectively, our continuing task, has been enhanced over the past decade especially by the availability of new devices. Where before we had the textbook and laboratory manual, blackboard and overhead projector, now we have textbooks in color, laboratory modules, video tape, slides and reliable projectors, film loops or cartridged reels and projectors, reliable audio tape cassettes and play-back devices, and even re-usable "sound sheets" with printed information on one side and a recorded audio signal on the other, to mention a few of the recent developments.

Some of these merely required logistic changes in the marketing procedures of publishers, such as is the case for laboratory modules. Some were probably due to the forces of competition, such as the colored textbook pages. Some resulted from an adaptation of products originally intended for other markets, such as the Moebius looped films for amateur home photographers. Still others represent the culmination of engineering and design activities of considerable sophistication, such as the portable video tape devices. But whatever the source, it remains our challenge to use these tools well.

It is the purpose of this paper to suggest that efficacious use of these tools more often than not will be enhanced by sensible incorporation of performance objectives (1) (2) into the interactive system, into the planning, when it appears otherwise appropriate to take advantage of new, or old but unfamiliar, teaching devices. Indeed, as one reads the literature published in the Journal of Chemical Education alone over the recent years, beginning with Lagowski (3) and continuing (4), (5), (6), (7), (8), (9), (10), (11), (12), (13), (14), (15), (16), (17), (18), (19), (20), (21), (22), (23), it is evident that knowingly or unknowingly many innovators have used performance objectives as they developed their own versions of an exciting idea for teaching chemistry better.

An example taken from our own work will illustrate:
Consider the teaching of a simple laboratory technique such as elementary glass manipulation, the preparation of a "ell" bend in a glass tube. Starting from zero, how many <u>different</u> operations must the student perform well in order to achieve a moderately acceptable result? By our count, more than twenty-five. These include:

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1. Lighting a match. (Too few habitually close the cover of a paper match book before striking a light.)
2. Inspecting the (probably aged) rubber tubing for tiny cracks before installing it between the gas outlet and the burner inlet.
3. Scratching the glass tubing, prior to severing off a suitable length.

This list need not be extended here, readers can as well supply their own additions, and the total will exceed twenty-five. (It is no wonder why so few students succeed in making an ell bend even after several attempts.) That is, at least in our experience, when we attempted to teach students how to bend a piece of tubing, and were unaware of the rather large number of different operations, almost all of which were brand new to the student, but to be mastered by the student, we were disappointed often enough in the students' lack of facility. Now, knowing the identity of the several new and different operations, the measured results demonstrate that the teaching is more effective (or the students currently possess inborn facility that they formerly lacked).

At the risk of appearing trite, we state the obvious: Facility requires mastery of detail. Often, the details to be mastered are well-hidden from both the student and the professor. Since we cannot expect many students to ferret out details whose very nature is unknown to them, it is the responsibility of the professor to undertake their explicit identification. One of the best ways to fulfill this task is to use performance objectives. Clearly, this applies to any pedagogical task, traditional or innovative in mode. If the professor knows what he will propose to measure in the students, identifies those observables explicitly, and is further aware of the inferences he will make about student attempts to perform, successfully or unsuccessfully, and informs the students of the actions he hopes to see them carry out, effective learning is more likely to be achieved. To the degree that the details remain unrecognized by the professor, the more difficult and distracting it will be for the student to guess and flounder while struggling to learn.

All this does not, however, say that students only learn when the above procedures are carefully followed. Quite the contrary. Almost all of us have had students learn in spite of what we did, or did not, do. In the determination of the percent composition of and "unknown" solid, such as the well known soda ash determination, beginning with a primary standard solid to be weighed, followed by the preparation of a secondary standard solution calibrated against the primary standard, and ending with the weighing and dissolving of the unknown, and another titration, some students do rather well. Indeed we do not need to know the identity of the more than one-hundred different operations, all new to the student; it is only the student who needs to concern himself. We suggest that the learning process can be expedited when the professor is aware, and one way or another teaches to that end.

Our second thesis is perhaps even less subtle. When one designs the use of a new teaching technique, explicitly stated performance objectives serve as discriminators, suggesting that this new device, or that, is better suited than some others. For example, consider the general problem of teaching laboratory technique. The obvious choice is to ask an experienced chemist to go through the steps in front of a film or video tape camera and use the result as an instructional tool for the student's viewing. In such a product, the student indeed sees what is to be done, but the large number of different operations, new to him, precludes effective learning on his part. An action that takes place in a few seconds on a viewing screen may very well involve five or six different operations, all of which pass by too fast. If students would review such presentations, perhaps they could learn the several different operations, but our analysis suggested that we use a different media, slides, to present the matter to be learned.

By their nature, slides are patient and will wait until the student is ready before changing (if one allows the student to control the slide-advance button, which we think is essential). Slides have another advantage over film in that they are easier to edit when a change is deemed necessary. Further, initially it is usually easier for the amateur to take several shots of the same scene, each differing slightly, and then pick the best one for the final set of slides, compared to the difficulties the same amateur experiences in shooting several movie scenes, and editing the best of these into a final sequence. Video tape editing is less clumsy, but even here slide editing has more than a slight advantage for the amateur.

In other teaching situations, such as a presentation of, say, the reaction of sodium and chlorine, the same systems-oriented planning all but precludes the suitability of slides and strongly suggests color film or color video tape, despite the practical difficulties with these media.

Assertions about the preferential suitability of slides for one pedagogical strategy and movies or video tape for another need some buttressing with evidence. Currently, our studies on the effective utilization of a multi-media approach using slides and audio tape cassettes are complete and a brief report is in order. In summary, teaching of elementary laboratory technique (simple glass handling, weighing to within 0.01 gram, filtering, using volumetric equipment, gas handling, pH measurement, molecular weight determinations, etc.) by slides and audio tape cassettes, prior to undertaking the work in the laboratory, is useful. Students set up equipment in half the time formerly required, and on examinations demonstrate improved competence in their knowledge of chemical concepts, even though these are all but totally excluded from the pre-laboratory instruction.

This conclusion is based upon evaluations of prior and post tests of 176 students, as well as their actions in the laboratory, divided into four equated groups. One group was a control group and the other three submitted or were subjected to the multi-media exposure on a voluntary, student selected basis, enforced attendance in small groups from one to three or four students at a time, and enforced attendance in a classroom with approximately 45 students present. Detailed results of course varied slightly for the three experimental groups, but all three demonstrated substantial improvement compared to the control group. (It is refreshing to report, however, that even the control group population learned a satisfying amount--apparently our traditional system of laboratory instruction is effective!) The complete study is reported in greater detail elsewhere (24).

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SHOULD THE KELLER PLAN BE BOUGHT WHOLE HOG?

by

Edward K. Mellon* and Grace S. Hall*

In this presentation we would like to describe a laboratory program recently implemented at the Florida State University which bears many similarities to the Keller plan. We feel it is important to point out why we made significant modifications to the Keller plan in the design of this course. The second portion of the paper will be devoted to our opinions on the advisability of a <u>total</u> conversion from present educational modes to what the educationalists call the "systems approach to education", of which the Keller plan is an example.

Opportunity for educational reform, in the form of an administrative dictum to shift to the quarter system from trimesters, came to the chemistry faculty at the Florida State University a few years ago. Our present chemistry offerings for first-year science students are summarized in Figure 1. The program we describe is the third quarter laboratory. What

| QUARTER | ONE | TWO | THREE |
|---|---|---|---|
| LECTURE | THREE HOURS | THREE HOURS | THREE HOURS |
| RECITATION | ONE HOUR | | |
| LABORATORY | | SIX HOURS | SIX HOURS |

Figure 1.

once was sophomore quantitative analysis now survives as a six-hour per week course in volumetric quantitative analysis. In contrast to most traditional, general laboratory programs we are in the fortunate position to be able to specify a small number of skills we wish the students to master, thus the modification of the traditional organization using systems approach ideas seemed the natural path to follow. Some time in his early college years a

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student should begin to develop independence, therefore, we thought the course should have a self-paced component (lack of rigid time deadlines). Student input led us to believe that they share this belief.

The laboratory is organized in the following way. On the first day of classes the student is issued the quality and quantity standards for A, B, and C grades and told to plan his laboratory work to earn the grade he wishes. The early portion of the course is factored into a number of simple units; for example, how to use a pipet or how to weigh by difference on a single pan balance. Since we assume all members of the class begin at the same point, it is possible to have a graduate teaching assistant present class demonstrations of each simple skill. These are followed by immediate application sessions in which students are individually monitored on performance by a graduate teaching assistant or faculty instructor. (Although we are developing audio-tutorial materials on these skills, they will be used for remedial work only; we intend to retain this valuable on-the-job training for the teaching assistants.)

Experimentation begins with standardization of an NaOH solution using a primary standard and a visual indicator. The student has two options: choosing a HCl solution of unknown concentration (a "confidence unknown") which contributes nothing to the final grade--but allows refinement of technique--or proceeding directly to an acetic acid unknown which does count toward his grade. Calculators are available, consequently the student can determine and report his results and have a graded report within one laboratory session. At this point, the instructors work individually with students who are not up to par in accuracy and precision in order to trouble-shoot for performance flaws. It is our opinion that this feedback loop of rapid grading and the human contact to provide maximum positive reinforcement is of <u>utmost</u> importance. An individual repeats his titrations until the instructor is satisfied the student has mastered the required skills. To insure a C grade, the student then performs a number of potentiometric experiments and a redox standardization. At this point the student is free to check out of his desk if he is satisfied with a C, but most students go on for a higher grade.

The student finds that he needs and is given less instructional aid in performing B-level work. To stress further independent work at the A-level, the student has the option of choosing among a number of available experiments, or of designing his own experiment.

The important point to be made about this course is that we <u>modified</u> the Keller plan to fit both the nature of the material and local constraints. The Keller plan is totally competency-based and allows the slower student the option to complete unfinished assignments in a new term. Although our course is self-paced, a specific date is set for course termination; we issue very few incomplete grades. While the Keller plan factors material arbitrarily into one-week chunks, we spend the whole first portion of the course ensuring that the student has become competent in volumetric techniques, and then allow the good student to choose among a number of options. While the Keller plan assumes a constant amount of instructional aid for students, our program requires more self-reliance from the student as he progresses. The nature of quantitative analysis allows us to use performance-based examinations (individual demonstrations, unknowns) rather than the written objective examinations common to the Keller plan. Lectures in the Keller plan are usually peripheral and poorly attended; early in our course the first part of each lecture is an experimental briefing. Those students ready to attack the days' work then go to the lab with the teaching assistant while those who feel the need stay with the faculty instructor until their questions are answered satisfactorily. In contrast to the Keller plan which generally uses the "pyramid system", we have both a faculty member and an assistant present in the lab during the early part of the course when student needs are greatest.

From the experience with this course our conclusion is that the Keller plan, suitably modified for local conditions, offers an opportunity to make substantial improvements in laboratory courses where ultimate skill levels are easy to identify.

The suggestion has issued lately from a number of quarters that the Keller plan is the educational panacea and that traditional forms, such as the lecture, are doomed. Having described an example where the modified systems approach clearly paid off, I would like now to discuss total conversion to such a plan.

Critics of the lecture system generally focus on the worst possible examples of lecturing: thousands of students packed into badly illuminated lecture halls, illegible blackboard writing, mumbling, faceless lecturers adept at disappearing at the end of the lecture, and true-false mystery exams which bear no discernible relationship to the material "covered" in the course. There is no doubt that these worst aspects of the lecture system represent a criminal educational mismanagement and must be overhauled. It is also possible to run the lecture system well--all of us can recall college experiences where this was done--so that interaction and feedback between students and faculty is maximized. Self-paced individualized discovery learning has always been a part of our M.S. and Ph.D. programs.

It's convenient to factor the teaching and lecturing processes into a short-range training function and a long-range education function. The systems approaches, such as the Keller plan, are superior in training students and should be the method of choice for that purpose. Although the drive and competence of the student plays a large part, faculty-student contact, even in lectures, seems to be one of the most important factors in education.

The prospect of total conversion to the Keller plan must be considered carefully:

1. An extensive cost analysis should be made before launching such a conversion.
2. Once the very time-consuming conversion has been made, sweeping course revision is more difficult.
3. The conventional Keller plan almost forces the use of objective testing; freedom of the instructor to employ a wide variety of testing methods where students actually do things rather than filling spaces on an IBM sheet would seem to be curtailed.

4. Once enthusiasm has evaporated for the new approach, it seems possible to have it degenerate into a particularly arid system.
5. The Keller plan is a forgiving system: The slow student (what we used to call the poor student) is allowed to inch through to completion of a course over a time span of two or more semesters. Perhaps in these hard times, it would be a kindness to advise such a student that a berth in medical school or graduate school may not be a realistic career goal. Traditional modes of grading have been effective in this regard.
6. A young instructor brought on the scene to manage an operating system would miss the personal development which we all experienced as young lecturers-we all learn by teaching.
7. In many cases the physical plant is ill-designed for a total conversion.
8. Finally, the pyramid plan seems particularly likely to lead to isolation of faculty from students. Also, total conversion would seem to place an unmanageable burden on upper classmen.

To us the most appealing model involves loosening up the lecture system, so that those easily identified skills, such as equation balancing and simple stoichiometry, are handled with self-paced systems. This would allow the number of lectures to be reduced, and it would ensure that all students in a lecture class have a common background--this we consider to be a major advantage. In these circumstances the lecture could serve its best function: the presentation of exciting material in an interactive fashion to students who are all ready to learn.

In summary, we think that systems approaches, such as the Keller plan, offer a superior solution to the problem of training students in simple skills. The retention of other modes of instruction such as the lecture is appealing since, in general, they allow the student to learn (or not to learn) from a random selection of human teachers. It appears that flexible use of several instructional modes, with the provision of faculty-student contact, is the best means to ensure that we continue to turn out educated students. One of the strengths of chemical education at the college level in the United States is the opportunity for each instructor to arrange the transmission of course content in those ways most suited to his personality. Thus if the Keller plan should not be bought whole hog, it most certainly offers a generous slab of bacon.

Finally, we do not consider that time-based systems are completely valueless. We close with a suggestion for the reform of college football. It is cruel and heartless to force football players to perform under pressure during a two-hour period on Saturday afternoon. After all, not every player may be in the mood to play ball. The present athletic system is time-based, in that it measures what a team is able to do at game time, and fails to measure what a team may ultimately be capable of when pressure is off. We suggest, then, a competency-based system in which individual members of the team go at various athletic self-paced tasks all through the week. A player can, of course, try a task as many times as he chooses. Since many players will wish to put off their tasks for personal reasons, the winning team in each game is not decided until far beyond the football season. Want to guarantee your home mortgage with the gate receipts??

# A COMMUNITY COLLEGE'S TOTAL APPROACH TO INDEPENDENT AND INDIVIDUALIZED INSTRUCTIONAL STRATEGIES: THE CANADIAN SCENE

by

Douglas K. Jardine* and Raymond Sloan**

In the United States and Canada, there are today many colleges that are experimenting with innovative ideas, and in almost all cases it's just that: an experiment by some faculty to make the learning environment more effective for their students. While there may be several experiments taking place in a given college at any one time, in institutional terms this is a piecemeal venture; there are only a few colleges which have ever declared a total commitment to the use of what are referred to as innovative instructional strategies. Mount Royal College is one of the few and the only one in Canada; it is in my opinion the current centre of educational excitement in Canada.

In reality, the excitement began in 1967 when a small United Church College that had served the city of Calgary for over sixty years became a public institution. Simultaneously with this change of ownership there came a new Board of Governors who installed a new President who in turn obtained the go-ahead to construct a new campus. The services of an educational consultant were retained and the Board of Governors accepted his proposal that this new campus be one employing a variety of innovative instructional strategies. The end result of this transformation was a new eighteen million dollar campus which opened to about 2700 F.T.E. in the Fall of 1972.

To effect such a transformation, there are three conditions to be met: the first condition is the institutional acceptance of an educational model which is to serve as the guide for curriculum design and development. The second condition is one of commitment by both faculty and administration to the implementation of the model. The third condition I refer to as the management condition.

The subject of this paper is the educational model used at Mount Royal and the second condition is simply common sense. The third condition should be addressed by a separate paper, but because of its importance I feel impelled to make the following observation. Experience in industry has shown that: if an institution has nothing going for it except one thing--good management--it will make the grade. If it has everything except good management, it will flop. This is also true in an educational setting, but what educators don't seem to yet realize is that the industrial management strategies that effectively optimize the production of widgets do not apply to the creation of an optimal learning environment. The condition for success is therefore management based on the recognition that a college's prime resources are its students, faculty and staff; in a word, people.

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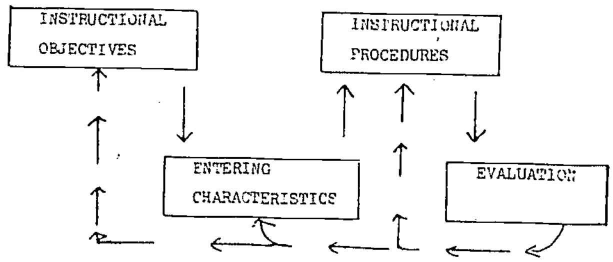
To be of any value, an educational model must be specific; yet it must be flexible enough that faculty members can feel comfortable and be themselves as they apply it to their particular teaching-learning situations. At Mount Royal a model was defined, (Figure I) the utter simplicity of which

Figure I




EDUCATIONAL MODEL

belies its ability to serve as the framework for significant change. On the premise that a college exists to facilitate learning through the establishment of an optimal learning environment, the model identifies the four factors of which a learning environment is a function.

It says that a good learning environment can be established for a course, for a module of a course, for a lecture, for a seminar, for a lab, for any part of the curriculum if:

<u>one</u> the objectives are determined and published;
<u>two</u> the initial status of students is assessed relative to these objectives;
<u>three</u> instructional procedures, based on the results of step two, are designed to help the student attain the objectives; and
<u>four</u> the students' attainment of these objectives are determined by evaluation documents that are directly related to the objectives.

The consultant's proposal imposed on this model an independent study component which was interpreted to mean students working on their own to discharge learning responsibilities that had been specified by the instructor. On the surface this seems to imply a behavioural philosophy to learning; the College could have gone in that direction, but fortunately it did not.

The model was applied to curriculum planning by, <u>one</u> identifying the top priority courses for the 1972 new campus opening. This turned out to be one hundred and seventy of the three hundred and sixty that were in the calendar; <u>two</u> dividing this workload amongst the one hundred and ten full time faculty;

and three requiring that each redeveloped course be seen to satisfy the model.

As articulated to faculty, this third point meant that instructional objectives were not required to be stated in behavioural terms. Rather, the course material had to be seen to contain statements of what was expected of students in order to successfully complete the course. As it turned out, several of the faculty produced objectives that bordered on the behaviourist's dream. More important was the fact that the door was left open to work with those faculty who felt unable to write out what they expected of students in their courses.

In the case of the instructional procedures factor, we worked from a different point of view; instead of substituting one instructional procedure for another, e.g., programmed learning for lectures, we attempted to provide at least two different ways for students to achieve any given set of objectives. We took this view because the research shows that instructional procedure A is never significantly more effective than B, regardless of what the A and B represent. It seemed to us then that the thing to do was to make available both an A and a B, and if possible, a C as well. So, for the instructional procedure factor, faculty were required to have their redeveloped course materials provide students with a choice of at least two ways to achieve any subset of the instructional objectives; it was expected that an independent study component would be included.

The evaluation factor was one wherein the faculty were asked to be more honest with the student by ensuring that evaluation items did relate to the instructional objectives. They were asked to include in their course materials the tests, quizzes, examinations that they planned to use, not necessarily revealing these documents to students before they were formally assigned. Some faculty did reveal them immediately because it was their way of stating instructional objectives. A few of the faculty adopted the learning for mastery concept for their courses, using both formative and evaluative documents in their evaluation procedures. While it seems peculiar to prepare evaluation documents long before the course is offered, it is quite an effective way of establishing course standards that are less biased by your knowledge of the students.

In applying the model to the curriculum we generally refrained from using consultants; we chose instead to send our faculty to places where they thought something interesting was being done. The Dean of Arts, Science as well as Research and Development became in-house experts on learning systems; more important, they got out from behind their desks and devoted their energies to working with and helping faculty resolve problems that arise in the development process. In the final analysis, it was the Dean and the faculty member who jointly determined that the course materials did or did not satisfy the model.

One of the results of applying the model was the increased emphasis on learning, that is having students successfully complete courses. This resulted in the creation of the I-grade which was assigned when a student had not achieved all of the instructional objectives. It was a way in which a student could get the additional time he or she required to achieve the instructional objectives. Simultaneously, the incongruity of the F-grade became obvious, and without any edict was used less and less by the faculty. This I-grade policy allows students sixty days after the mailing of semester grades to remove the I-grade by completing the course; after that, the I-grade is permanently on the transcript and the student must reregister in the course in order to be able to complete the course and obtain his credit.

Another spin-off of the model was the development of the concept of open space. This concept is based on the premise that if students and learning resources are brought together, the probability of a student learning is increased. A shopping mall concept was chosen for the new campus and it was determined that the single building would be U-shaped with all the learning areas on the outside of the U, and all other services, such as restaurants, banks, pool halls, faculty lounges, etc., would be on the inside. The open space, equivalent in area to three football fields, has faculty offices, the library and other media resources located at Learning Resource Islands, as well as student study spaces diffused throughout. Each learning resource island serves as a focal point for the distribution of hardware and software related to the courses assigned to that island. Faculty associated with these courses are assigned offices in close proximity to the island.

As an example of the model in action, I shall outline part of the structure of two one-semester long courses that are the core of the first year curriculum in a two year Environmental Quality Control Program. Amongst other things, this program undertakes to produce a graduate who is able to work with a minimum of supervision in the general area of environmental quality control. As a result we designed the first year core courses of the program in such a way that students time and again went through the process of defining a problem, analyzing this problem and synthesizing solutions to the problem. We set this as a higher priority than one wherein every student would have had an identical set of learning experiences.

The first semester would make a strict behaviourist go mental. We examined the environment and the environmental problem from several perspectives; we had sociologists, psychologists, geographers, lawyers, economists, industrial personnel enter into lecture-panel discussion sessions with students on the subject of environmental problems. A number of these were organized by the students and were open to the public. At the same time, the students made use of self-instructional materials, audio tapes and assignments to achieve a set of ecological, biochemical and chemical instructional objectives that had been chosen and laid on by the faculty.

The students worked at achieving these objective independent of lectures and at their own rate; evaluation of a student's performance on a test was independent of the performance of the other students.

For a lab program, we negotiated with students, either as individuals or in groups, the specifics of three projects; the main thrust of one would be biological or ecological, one chemical and the third in any area that interested them. Those with ideas, took little of our time, and for those with no ideas, we devoted considerable time to helping them discover a question that tweaked their curiosity. This approach to the lab program allowed us to individualize part of the course to the needs of individual students. It meant that we did not have to lay on all students a schedule of basic analytical experiments even though most of the students had no previous laboratory skills. Instead, we took the position that the best time for the student to learn, for example basic volumetric skills, was when his project demanded these skills of him. We found this to be very effective and is simply an application of what the educational psychologists have been saying for years: a person learns by doing and learns best when he needs to know.

In the second semester, in addition to the independent study component, the students were split into two groups; one assigned to a cement plant and the other to a gas plant. Each group of students sub-divided themselves into four teams to consider:

<u>one</u> the physical and chemical processes of the plant that are associated with the production of pollutants.
<u>two</u> how the pollutants are dispersed
<u>three</u> effects of the pollutants, on the surroundings
<u>four</u> measurement of pollutant concentrations

Each group chose from amongst themselves, a group leader and four team leaders. Once again, contracts were negotiated with each team that specified the goals, and how they were to be approached. The faculty played the role of senior executives in an environmental consulting agency; the group and team leaders were viewed as middle managers. Thus, it was the students who established liaison with the plant personnel. One team of students even arranged for themselves to work in the gas plant's environmental control lab for a month. The end product of these efforts was a written report from each team and a seminar led by each team. These seminars were compulsory for all students and while the seminar givers were not evaluated, the audience were subjectively evaluated on the quality of their participation. The report was evaluated as being either acceptable or unacceptable; all reports deemed unacceptable were discussed with the team and its shortcomings detailed so that it could be reworked and resubmitted.

In terms of letter grades, the profile for the first semester is shown in Table I. The F-grades were students that for one reason or another did not

<u>TABLE I</u>

First semester grade profile

| | |
|---|---|
| A-grades | 3 |
| B-grades | 6 |
| I-grades | 18 |
| W-grades | 17 |
| F-grades | 14 |
| TOTAL REGISTRATION | 58 |

sign a withdrawal form. About half of the original students chose not to register for the second semester, even though under the college's open door policy this was their privilege regardless of their performance in the first semester. On the other hand, Table II, about two-thirds of the students

TABLE II

| Grade profile of students registering in second semester | | # completing second semester |
|---|---|---|
| A & B grades | 9 | 9 completed |
| I-grades | 13 | 9 completed |
| W-grades | 2 | 1 completed |
| F-grades | 4 | 0 completed |
| new students | 3 | 0 completed |
| TOTAL REGISTRATION | 31 | |

registering for the second semester had not completed the first semester. What is most interesting is that about seventy per cent of the I-grade students from the first semester did successfully complete the second semester. The grade profile for the second semester is shown in Table III. By a process that I call natural selection, the program had nineteen serious, competent students at the end of the first year.

TABLE III

| Second semester grade profile | |
|---|---|
| A-grades | 7 |
| B-grades | 12 |
| I-grades | 6 |
| W-grades | 6 |
| F-grades | 0 |
| TOTAL REGISTRATION | 31 |

But grades don't show how the attitudes of the students had shifted; their approach to environmental matters became more that of a professional than that of a concerned amateur. They were capable of working on their own, seeking out information and learning the skills that they needed to get a job done. But as well, they had learned the value of teamwork and had learned how to work as a member of a team. These characteristics were amply demonstrated in the summer jobs that they held, and in particular by four students employed by government agencies, three of whom were very much on their own in a field situation; the fourth, placed in charge of third year university students, was managing a section of a quality control laboratory. In summary, we feel that without the independent and individualized components of the curriculum, the students would not have been as well prepared.

SIMULATED CHEMICAL EXPERIENCES

USING RANDOM-ACCESSED SLIDES

by

Rod O'Connor*, Michael Bell** and Paul Glenn**

An important segment of the laboratory experience in chemistry involves learning to make careful observations, useful notes, appropriate deductions, and efficient choices. Although such learning is, perhaps, most meaningful in the setting of a real "hands-on" involvement, which integrates all segments of the laboratory experience, it can be developed through simulation as a supplement to "live" laboratory work.

Simulated laboratories may use a number of different formats. Simple linear simulations by television or motion pictures can take the student through an experimental sequence, on a real or altered time scale, after which he may be provided with data or observations for treatment and analysis. Computer-simulations may add randomly-generated data or opportunities for choices of reagents, conditions, or procedures with access to results and complications from the choices made. The "branching" capability of computer programs can be attained, on a limited scale, by the inexpensive and easily-produced 35 mm slide programs designed for random-access projection. The advantages of such programs, in addition to low cost and simple production, include their adaptability to either group or individualized instruction and the simplicity and rapidity with which they can be modified and revised.

Programs require careful planning to incorporate reasonable selections of choices (with their results). For preliminary testing, hand-drawn and lettered artwork is recommended since this can be filmed at a very modest cost in time and supplies. After testing and revision, these "quick-and-dirty" slides form the storyboard for a more professional program using actual photographs and high quality graphics.

Audio tapes can be used to introduce slide programs or to accompany linear segments of the simulation. Of critical importance is the need for students to take careful notes throughout the program in the same way that they would do in a good "real" laboratory situation.

Ideally, branched simulations on slides use projector systems specifically designed for random-accessibility (e.g., the Eastman Kodak Random-Access projector), but they can be used with any carousel or linear tray projector by depressing the "select" button to move the tray to the slide number desired.

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Ten 36-frame programs on qualitative analysis have been developed and tested by the authors. Copies of the storyboards are available, at cost, on request. Class-testing has demonstrated that these simulations do improve student skills in making observations, taking careful "laboratory" notes, and interpreting experimental results. In addition performance efficiency in real laboratory situations based on related experiences is improved.

## COMPUTER-BASED INSTRUCTION

### INTRODUCTORY REMARKS

Bassam Z. Shakhashiri

Many institutions have experimented with the use of computers to enhance instructional programs and to increase educational productivity. In all levels of education as well as in vocational training, computers have been used to achieve a wide range of purposes including assistance to students in and out of the classroom and laboratory. The impact of computer technology on education is far reaching, but it is yet to be fully realized. The student's ability to interact with the computer allows him benefits that cannot be obtained by any other method of instruction. Yet, computer-based instructional programs are not and should not be used as the sole means of instruction.

The advantages and disadvantages of using computers in chemistry instruction are discussed in the following papers. The University of Texas and the University of Illinois are major pace setters in the use of computers for instructional purposes. Numerous chemistry instructors all over the country have been involved in developing software for use in undergraduate courses. The Texas system and the Illinois PLATO (Programmed Logic for Automatic Teaching Operations) system are described in detail. Both systems were demonstrated "live" via telephone hookup during the afternoon session of the Symposium. The other papers reflect the widespread use of computer technology and its effectiveness in undergraduate instructional programs.

THE IMPACT OF COMPUTER-BASED METHODS ON CHEMICAL EDUCATION

by

J. J. Lagowski*, G. H. Culp*, and S. J. Castleberry*

Many of the procedures and techniques employed by instructors at large universities are controlled and necessitated by logistical considerations: large numbers of students, low numbers of instructors, classroom space, and record keeping. There have recently been numerous attempts to return control of the educational process to the instructor and student: the Keller Method (1) (PSI) audio-tutorial tapes, CAI (computer assisted instruction), CGRE (computer generated, repeatable exams), CMI (computer managed instruction) and CAL (2) (computer augmented lecture), to mention just a few.

We have attempted to combine some of these techniques and apply them to a general chemistry course. This paper will present these techniques, the results we have obtained, and the changes and adaptions which we think will be useful.

The techniques we have employed are a combination of CMI, CAI, PSI, contingency management, (3) and self-paced, individualized instruction. In combining these techniques and designing the course, we have made the following assumptions: (1) the optimum conditions for learning are unique for each student; each student can learn more effectively when the sequence of instructional material, the pace and mode of presentation and the style of instruction are tailored to his individual needs and capabilities. (2) An integrated system of human, hardware and software components presents the only viable method to offer large numbers of students highly individualized instruction. Planning (4) the utilization process for human components of a system must be completely integrated with the planning of machine and software utilization. The hardware/software functions are to present instructional material, collect data, analyze data, reduce data, and provide reports. See the paper by Culp et al. in this symposium for a description of the way in which such programs can be written. The human functions include designing teaching strategies, interpreting data, counseling students, bridging the gap between existing software and current research, and obtaining behavioral objectives in the affective domain (i.e., influencing attitudes, motivating and inspiring students). To a large extent the computer can perform many of the tasks (on an individual basis) now performed by humans, as well as, or better than the instructor. To allow large numbers of students to proceed through a self-paced course, taking different tests and modules at different times requires an automated record keeping system. To meet this requirement we implemented a CMI, contingency management system, which could automatically record computer administered test results, automatically record CAI module results, accept non-computer generated results, and provide student progress reports in the form of individual profiles on demand. This allows

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both the instructor and the student to know exactly the student's status at any given time.

In order to understand the implementation of the system, it is necessary to know the structure of the course as taught by one of us (JJL) incorporating these general ideas. Figure 1 is a copy of the first handout the student

CHEMISTRY 302.12265 - FALL 1972
J. J. Lagowski
TTH 3-4:30
CHE 15

Text: Slabaugh and Parsons, GENERAL CHEMISTRY, Second Edition
Chapters 7, 8, 9, 10, 11, 12, 13, 14, 15

Work Distribution:

1 Hour lecture every Thursday.
1 Discussion period every Tuesday (schedule to be announced).
1 Session/week with computer (to be scheduled at your convenience).
Examinations: 3 October, 8 November, Final Exam Period 21 Dec., 9-12 am. Exams are scheduled for the evening of these days, 7:30-9:30 pm. In case of a conflict, please see me at least one week before the exam and individual arrangements will be made.
Quizzes: End of each lecture of Thursdays.

| Grading Schedule: | Points | Total |
|---|---|---|
| 3 Major examinations | 100 each | 300 |
| 10 10-minute quizzes | 10 each | 100 |
| 12 Attendance at discussion periods | 3 each | 36 |
| 12 Attendance at lectures | 3 each | 36 |
| 14 Tutorial Modules | See list | 150 |
| 7 Simulated Experiments | See list | 160 |

A = 100 - 90%
B = 89 - 80%
C = 79 - 70%
D = 69 - 60%
F = 59 and below.

Fig. 1

Figure 1. Information given to student at the beginning of the experimental course.

receives; it shows the text and chapters used, the work distribution, and the grading schedule. The course consisted of one hour of lecture per week, one hour of small group discussion and one hour of computer interaction per week (the actual computer time varied with the needs and desires of the students). The three major examinations and ten quizzes were instructor generated, administered, and graded in the usual way. However, for each question on each test there was a corresponding test module on the computer which the students could use to make up low scores received on the paper pencil test after doing individually prescribed remedial work. The computer test modules used random parameter generation techniques to insure that no two students received exactly the same question and that no student received exactly the same question on repeated trials. The computer administers the test, scores it (immediately giving the student his results) and then records the results in the student's data file.

Figure 2 shows the computer modules (tutorial/drill and simulation)

CHEMISTRY 302.12265 - Fall 1972
J. J. Lagowski

TUTORIAL MODULES

| Chapter | Code | Description | Points |
|---|---|---|---|
| 7 | CHEM1 | The Gas Laws | 15 |
| 9 | CHEM114 | Henry's and Raoult's Law | 10 |
| 9 | CHEM60 | Heat of Vaporization | 10 |
| 9 | CHEM61 | Kinetic Molecular Theory Applications | 10 |
| 10 | CHEM116 | Colligative Properties | 10 |
| 10 | CHEM113 | Solution Concentration | 10 |
| 10 | CHEM2 | Solution Stoichiometry | 10 |
| 11 | CHEM119 | Equilibrium | 15 |
| 13 (thru 13.5) | CHEM107 | pH, $[H^+]$, pOH$[OH^-]$ | 10 |
| 13 (thru 13.9) | CHEM124 | Common Ion Effect | 10 |
| 13 (thru 13.9) | CHEM126 | $K_{sp}$ | 10 |
| 14 | CHEM36 | Redox Equations | 10 |
| 15 | CHEM109 | Elementary Thermochemistry | 10 |
| 15 | CHEM139 | Thermochemistry | 15 |

SIMULATED EXPERIMENTS

| Chapter | Code | Description | Points |
|---|---|---|---|
| 7 | CHEM3 | Molar Volume of $N_2$ | 25 |
| 10 | CHEM115 | Colligative Properties | 20 |
| 11 | CHEM32 | Reaction Kinetics | 25 |
| 13(thru 13.5) | CHEM122 | pH and $K_i$ Determination | 25 |
| 13(thru 13.9) | CHEM19 | Titration | 20 |
| 14 | CHEM127 | Faraday's Law | 20 |
| 15 | CHEM41 | Calorimetry | 25 |

REVIEW MODULES*

| Chapter | Code | Description | Code | Description |
|---|---|---|---|---|
| 6 | CHEM20 | Interpreting Formulas | CHEM105 | Formula Writing |
| | CHEM26 | Balancing Reactions | CHEM43 | Formula Weight |
| | CHEM27 | % Composition | CHEM44 | Mole Ratio |
| | CHEM29 | Interpreting Formulas | CHEM45 | Mole Concept |
| | CHEM30 | Formula Writing | CHEM46 | Wt/Wt Relations |
| | CHEM36 | Balancing Reactions | CHEM47 | MW of Gases |
| | | | CHEM48 | Volume-Volume Relations |
| | | | CHEM49 | Wt.-Volume Relations |
| | | | CHEM42 | Mole Concept |

*These modules can be used for review in the subjects indicated if you think you need it. No credit is given for working with these modules since they contain information which you should be familiar with.

Fig. 2

Figure 2. A list of tutorial, simulated experiments, and review modules available for the experimental course.

available to the students and their point value. The modules are also keyed to the appropriate chapter in the student's text. The effectiveness of CAI as a teaching tool has been amply demonstrated (5)(6)(7)(8). Likewise, the rationale behind its development and application in general subjects, and particularly in chemistry, has been well documented (6)(9)(10)(11). We shall therefore only briefly outline the philosophical points underlying our modules: (1) the modules supplement the instructor, not replace him; (2) the modules are designed to help students learn by doing, not necessarily to teach or merely transfer standard information; (3) the computer interactions are modular and independent, facilitating the individualization of student experience in pace, sequence and content.

A few sample interactions will illustrate these points. Figure 3 is a

```
THIS IS A SIMPLE PRACTICE SET ON THE IDEAL GAS LAW
WHEN YOU HAVE HAD ALL THE PRACTICE YOU WANT, TYPE 'STOP'.


CALCULATE THE PRESSURE OF A GAS GIVEN THAT ITS MOLE WT IS
 51.5 AND THAT 52  G OF THE GAS OCCUPIES 28231.2  ML AT
 68.6 DEG C.
 ? CALC
WHEN YOU HAVE COMPLETED YOUR CALCULATIONS, TYPE
RUN 1Ø9Ø

STOP AT 1Ø8Ø

*OK
PRINT(52/51.5)*.082*68.6/28.23 .2Ø1198

RUNØ9Ø
NOW YOUR ANSWER
 ? .2Ø1198
SORRY, NO.
YOU FORGOT TO CONVERT TO ABSOLUTE TEMPERATURE
REWORK THE PROBLEM AND ANSWER AGAIN.
 ? CALC
WHEN YOU HAVE COMPLETED YOUR CALCULATIONS, TYPE
RUN 1Ø9Ø

STOP AT 1Ø8Ø

*OK
PRINT\
PRINT(52/51.5)*.Ø82*(273+68.6)/28.23 1.ØØ188


RUNØ9Ø
NOW YOUR ANSWER
 ?1.ØØ ATM
I'LL ACCEPT THAT.
```

Fig. 3

Figure 3. A typical student interaction for a tutorial module (The Gas Laws) showing various answer processing strategies.

sample student interaction on the module CHEM1, the gas laws. First, the module randomly selects the type of problem; whether the student will solve for pressure or volume or temperature using the combined gas law. Then the module randomly generates the numerical value of the parameters to be given to the student. In the student's first answer he does not convert to absolute temperature, and the module is able to diagnose this error and give the appropriate response contingent feedback. On the student's second answer, he is correct and is given an appropriate positive response. Figure 4 illustrates what happens when the student inputs a series of answers which are incorrect, and the module cannot diagnose a specific

```
CALCULATE THE VOLUME OF 6 G OF A GAS GIVEN THAT ITS
PRESSURE IS 763.2 TORR, ITS MOLE WT IS 2Ø AND THE
TEMPERATURE IS 61.5 DEG C.
 ? 3Ø
SORRY, NO.
PV=NRT, R=Ø82 L-ATM/DEG
PLEASE ANSWER AGAIN.
 ? 40
SORRY, NO.
V=NR T/P, N=WT/MOLE WT = .3
PLEASE ANSWER AGAIN.
 ? 6Ø L
YOU BLEW IT AGAIN
V = .3 *.Ø82*334.5*76Ø/ 3 = 8.1942 L
```

Fig. 4

Figure 4. A typical student interaction for a tutorial module (The Gas Laws) showing additional answer processing strategies.

type of error. On the first response the student is given a broad clue; on the second response the student receives a more specific hint, and on the third response he is given the solution.

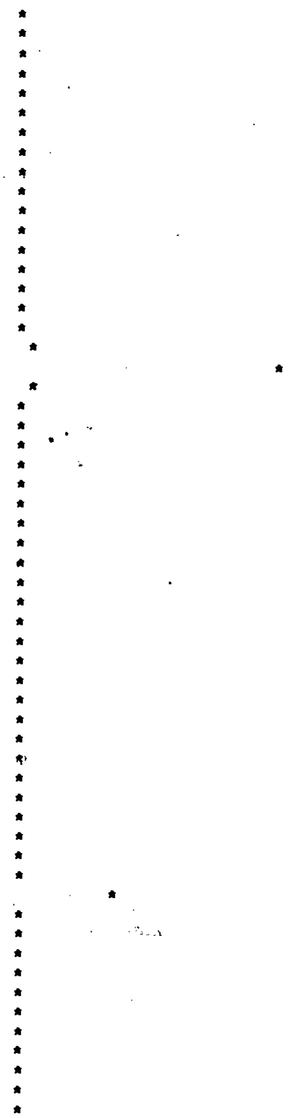
The above interactions illustrate a typical tutorial/drill type module; the following figures illustrate a typical simulation type module. Figure 5 is the initial interaction in CHEM32, a kinetics experiment in which the

```
YOU ARE BEGINNING AN EXPERIMENT SIMULATION IN WHICH
YOU WILL FOLLOW THE REACTION     A-> B

ENTER YOUR UNKNOWN NUMBER.
1234

THANK YOU.
IN THIS EXPERIMENT YOU WILL COLLECT
DATA WHICH WILL ENABLE YOU TO
DETERMINE THE ORDER OF REACTION AND CALCULATE THE
RATE CONSTANT AS EXPLAINED IN THE HANDOUT FOR THIS
EXPERIMENT.

IN ORDER TO OBTAIN THE APPROXIMATE DURATION YOU MAY
LOOK AT THE ABSORPTION SPECTRA AT SEVERAL DIFFERENT
TIMES.
WHAT CONCENTRATION (IN MOLES/LITER) OF A WILL YOU
USE FOR THE INITIAL CONCENTRATION?
.5
AT WHAT TIME (IN SECONDS) DO YOU WISH TO SEE THE SPECTRA?
10
```

Fig. 5

Figure 5. A typical student interaction for a simulated experiment (kinetics)

student's task is to collect sufficient data to determine (1) the order of reaction, and (2) the reaction rate constant. This module is really a series of decisions the student must make on the basis of his experience and the data he collects. He must decide the experimental conditions: concentration and the wave length at which to follow the reaction. Figure 6 shows the data upon which he makes the latter decision. He must decide if his data is satisfactory and how he is to treat the data. These decisions



HIT THE RETURN TO CONTINUE

Fig. 6

Figure 6. Raw data obtained from a simulated experiment (kinetic) for a typical set of student generated responses. The figure corresponds to teletype output with the wavelength axis being set vertically at the right. Absorbance is read horizontally from right to left.

are shown in Figure 7. After the student has analyzed the data (on or off line), he takes a special module which checks and records his results.

The course utilizing our C-BE methods has been offered twice as a regular section of general chemistry 302. We evaluated the course by: (1) comparing it to other non-C-BE sections in terms of student achievement;

```
AT WHAT WAVE LENGTH (IN CM-1) SHOULD WE FOLLOW THE
REACTION?
3500
EXCELLENT CHOICE.
WHAT TIME (IN SECONDS) DO YOU WISH TO BEGIN THE
OBSERVATIONS?
0
WHAT INCREMENT (IN SECONDS) DO YOU
 WISH?
10
<PARITY ERROR - LINE REJECTED>
5

AT WHAT TIME (IN SECONDS) DO YOU WISH TO END YOUR
OBSERVATIONS?
180

WITH WHAT CONCENTRATION OF REACTANT DO YOU WISH TO START?
.5

TIME      ABSORBENCY (AT 3500 CM-1)
   0.0         .4250
   5.0         .3684
  10.0         .3250
  15.0         .2908
  20.0         .2632
  25.0         .2403
  30.0         .2211
  35.0         .2047
  40.0         .1906
  45.0         .1783
  50.0         .1675
  55.0         .1579
  60.0         .1494
  65.0         .1417
  70.0         .1348
  75.0         .1285
  80.0         .1223
  85.0         .1176
  90.0         .1128
  95.0         .1084
 100.0         .1043
 105.0         .1005
 110.0         .0970
 115.0         .0937
 120.0         .0906
 125.0         .0877
 130.0         .0850
 135.0         .0825
 140.0         .0801
 145.0         .0779
 150.0         .0757
 155.0         .0737
 160.0         .0718
 165.0         .0700
 170.0         .0682
 175.0         .0666

ARE YOU SATISFIED WITH YOUR DATA?
YES
GOOD
WOULD YOU LIKE TO SEE A PLOT OF YOUR DATA?
```

Fig. 7

```
YOU MAY NOW OBTAIN EXACT ABSORBENCY DATA OVER YOUR
DESIRED RANGE OF TIME AND AT TIME INTERVALS SPECIFIED
BY YOU.

AT WHAT WAVE LENGTH (IN CM-1) SHOULD WE FOLLOW THE
REACTION?
3500
EXCELLENT CHOICE.
WHAT TIME (IN SECONDS) DO YOU WISH TO BEGIN THE
OBSERVATIONS?
1
WHAT INCREMENT (IN SECONDS) DO YOU WISH?
10

AT WHAT TIME (IN SECONDS) DO YOU WISH TO END YOU
OBSERVATIONS?
171

WITH WHAT CONCENTRATION OF REACTANT DO YOU WISH TO START?
.9

TIME      ABSORBENCY (AT 3500 CM-1)
   1.0         .7425
  11.0         .5782
  21.0         .4789
  31.0         .4125
  41.0         .3648
  51.0         .3290
  61.0         .3011
  71.0         .2788
  81.0         .2605
  91.0         .2452
 101.0         .2323
 111.0         .2212
 121.0         .2116
 131.0         .2032
 141.0         .1958
 151.0         .1892
 161.0         .1832

ARE YOU SATISFIED WITH YOUR DATA?
YES
WOULD YOU LIKE TO SEE A PLOT OF YOUR DATA?
YES
O.K.
WHAT KIND OF PLOT?
(X=MOLES REACTED, A=ORIGINAL CONCENTRATION OF A, T=TIME)

   A.   (A-X) VS T
   B.   LN(A/(A-X)) VS T
   C.   X/(A(A-X)) VS T
```

Fig. 7

Figure 7. A listing of raw data obtained from a simulated experiment (kinetics) for a typical set of student generated responses.

(2) determining costs per student hour; and (3) obtaining student attitudes. We controlled the comparison of sections for differences in entering skills and aptitude by using chemistry placement test scores and SAT-M and SAT-V test scores as covariables. Figure 8 shows the comparison data in terms of grade distributions. In these terms, the classes using C-BE

COURSE GRADE DISTRIBUTIONS

| | A | B | C | D | F |
|---|---|---|---|---|---|
| COMPUTER SUPPLEMENTED (1971)* | 70% | 9.7% | 6.1% | 1.2% | 13% |
| COMPUTER SUPPLEMENTED (1972)* | 44.3% | 17.7% | 4.2% | 1.4% | 21.1% |
| TRADITIONAL CLASS* | 10.4% | 25.6% | 18.4% | 14.4% | 31.2% |
| TRADITIONAL CLASS | 18.7% | 33% | 26.4% | 12.7% | 9.2% |

*Same Instructor

Fig. 8

Figure 8. The course grade distributions for two experimental computer supplemented courses and two traditional courses.

techniques achieved a greater proportion of A's and B's. Figure 9 shows our cost data. It is interesting to note that these costs are based upon

STUDENT USE COSTS

| | #JOBS | TM HRS* | COMPUTER COSTS | LINE COSTS | STUDENT HRS. |
|---|---|---|---|---|---|
| Fall 1971 | 2291 | 18.944 | $4925.48 | 1613.57 | 1613.57 |
| Fall 1972 | 7440 | 24.63 | | | |

| | COST/ STUDENT HR | RATIO STUDENT HR/TM HR | COST/ ACCESS | AVERAGE TIME/ ACCESS |
|---|---|---|---|---|
| Fall 1971 | 4.05 | 85/1 | -- | -- |
| Fall 1972 | 2.07 | 147/1 | $0.92 | 40.9 min |

*TM HRS = CPU HOURS + PERIPHERAL OPERATIONS TIME FACTOR

COMPUTER COST FIGURES ON THE BASIS OF $256/TM HR

Fig. 9

Figure 9. Student use costs broken down into relevant categories.

"research-rate" charges, not the lower, regular departmental charges. Even at this rate, it is possible to reduce costs by optimizing and improving the system as the drop from $4.05/student hour to $2.07/student hour indicates. We can easily foresee the costs dropping to less than $1.00/student hour when the current department rates are used rather than experimental rates.

At the end of the course an attitude scale consisting of 51 items was administered to the students. The maximum possible positive score was 193. The neutral score was 96.5. The mean score of the 79 responding students was 156.6, which clearly indicates a positive attitude of the student towards C-BE techniques. Figure 10 summarizes the attitude scale data. The alpha coefficient shown is the coefficient of internal consistency and reflects the degree of reliability among the items of a scale in terms of overlapping variance.

ATTITUDE SCALE

| | |
|---|---|
| Number of items | = 51 |
| Maximum possible score | =193 |
| Neutral score | = 96.5 |
| Scale mean for 79 responding students | =156.6 |
| Alpha | = .55 |

Fig. 10

Figure 10. Results obtained on a student attitude instrument given to the experimental class. A copy of the instrument is available from the authors.

Our results indicate that C-BE techniques can efficiently augment the teacher's efforts, and have a positive effect on both student achievement and student attitudes. In light of our results it is not difficult to foresee our general chemistry course becoming not one course but a different individualized "course" for each student, the content of the "course" (and hours of credit) to be determined on the basis of a placement test (on minimum core skills) and student desires (for optional units). The sequence and rate of progress of the student will be determined jointly by the teacher and student so that the course becomes self-paced within the limits agreed upon by student and teacher. The "course" is no longer constrained by the traditional time limits: semesters or quarters and credit hours. In this course, the teacher retains his usual teaching role, but trades the roles of bookkeeper, grader and all around paper shuffler for the roles of counselor and mediator.

## Acknowledgments

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# COMPUTER BASED INSTRUCTIONAL TECHNIQUES IN UNDERGRADUATE INTRODUCTORY ORGANIC CHEMISTRY: RATIONALE, DEVELOPMENTAL TECHNIQUES, PROGRAMMING STRATEGIES AND EVALUATION

by

G. H. Culp*, P. L. Stotter*, J. C. Gilbert* and J. J. Lagowski*

## Introduction

Computer-based instructional techniques are more and more becoming a regular reference topic in reports dealing with innovative educational methods. As more and more educators become aware of the techniques of computer-based instruction, it becomes appropriate to define a representative method employed in the design, development and evaluation of this form of instructional tool. We wish to describe some of the methods and techniques that we have used in the past 5 years at the University of Texas at Austin. Although the discussion will center about general and organic chemistry, the techniques described are applicable to almost any discipline. The topics related to computer-based instruction we will discuss are 1) Rationale 2) Developmental Techniques 3) Programming Strategies and 4) Evaluation.

## Rationale

Of the four topics for discussion, the rationale for using computer-based instruction is perhaps the most widely known. Phrases such as "easing the problems associated with the logistics of instruction," "individualized instruction," "self-paced instruction," and "relief from routine instruction for the teacher" have often been quoted in this regard. Of course, the basic rationale is one of improvement within the educational process.

All too often teachers become overly involved in attempting to help students learn in a poor environment rather than teaching; that is, they have the burden of assigning, grading and giving students feedback on homework and tests; helping students with their assignments; and conducting tutorial drill interactions. To a large extent, the computer can perform these tasks--and on an individual basis--as well or better than the instructor. This does not diminish the teacher's role in the educational process, but rather allows the teacher-student relationship to be richer in the activities teachers perform best: providing insight into difficult concepts, transmitting an understanding of abstract ideas, and inspiring students.

Computers may also be extensively used to measure entering skills, and a series of programs which may contain review materials, standard curriculum materials, and/or advanced placement materials may be prescribed. Computer

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programs may also simulate a variety of experiments, thus extending a student's laboratory experience to much greater depth than is usually now possible. Suitable experiments include those that require time compression/expansion, those which are too dangerous for beginning students to perform on a large scale in the real laboratory, and those which are too sophisticated and require too expensive an apparatus for wide scale use. We feel that computer-based instructional techniques are best when they a) supplement existing curricula; b) help students learn; c) help individualize instruction; and, d) are flexible in application and may be adapted to a variety of course designs.

In short, the rationale for computer based techniques is that their application has the potential of yielding a more effective and efficient instructional process.

## Developmental Techniques

Program development then is keyed to identifying the areas that fall into the categories described above and applying a systems approach in development (Fig. 1). Typically, a course is divided into units or segments;

DEVELOPMENTAL TECHNIQUES

The System Approach

Program Definition
↓
Quantitative Performance Objectives
↓
Task Analysis and Sequence of Instruction
↓
Construction of the Program
↓
Debugging and Pilot Test
↕
Revision
↕
Class Use
↓
Evaluation

Figure 1. The "systems approach" used in developing computer-based lessons.

each segment is further divided into subunits, or modules; each module is then defined in terms of performance objectives, with these objectives forming the basis of the strategy for the computer program. The sequence of instruction through the program is next defined in light of the performance objectives, and the program undergoes initial construction and coding into an appropriate computer language (through this point, development of the program has been entirely on paper). Following this, the program is punched onto paper tape or computer cards and entered into the computer, debugged, then pilot tested by 2-10 volunteer students. Any necessary revision derived from the pilot testing follows, and the program is made available for full scale use by a class and evaluated in terms of student performance and attitudes. We have found that this system requires approximately 25 man-hours for development per student contact hour.

Programming Strategies

We believe the optimum program length, at least as measured by the gluteal gauge, is in the range of 20-45 minutes. Consideration of this and a personalized, informal dialog between the student and the computer are the initial strategies incorporated into each program (Fig. 2). The student-computer

```
ORGANIC, OCH17

WHO IS THIS?
SAMANTHA

——→ O.K., SAMANTHA, LET'S SYNTHESIZE...

ELEMENTARY ALKENE RELATED SYNTHESES
```

Figure 2. An example of an initial student interaction with a lesson.

interaction should be pleasurable; one in which the student can experience a sense of comradeship and freedom between himself and this invisible, but real tutor. In this regard, options such as AID, SKIP, RESTART, or STOP provide student control of the program, thus preventing any sense of entrapment with the computer (Fig. 3). CALC is a specific option that allows

```
NOW,TELL ME...WHAT DO YOUR CLOSE
FRIENDS CALL YOU?
——→ IRENE

I HEARD THEY CALLED YOU SEXY-IRENE

NOMENCLATURE...ALKANES AND CYCLOALKANES
YOU MAY COMMENT, SKIP, RECEIVE ASSIS-
TANCE, OR STOP BY TYPING TALK, SKIP,
AID, OR STOP, RESPECTIVELY

DO YOU WISH TO REVIEW THE RULES FOR
NAMING OPEN-CHAIN ACYCLIC ALKANES?
```

Figure 3. An example of an initial student interaction and student options within a lesson.

the student to use the terminal as a calculator (Fig. 4). In addition, the

```
——→ CALC
I'LL KEEP IN THE CALCULATION MODE
UNTIL YOU TYPE...GO BACK...
EXPRESSION?

——→ (760*32.5*300)/(740.5*50*18)
RESULT  =       11.12
EXPRESSION?
——→ GO BACK
```

Figure 4. An example of using the terminal as a calculator during the course of a given lesson.

primary objectives are stated at the beginning of each program, as shown in Fig. 5, ensuring that the student is aware what is expected in terms of his performance within the program.

```
THE INTERPRETATION OF ELEMENTARY
NMR SPECTRA

THIS LESSON ASSUMES YOU HAVE HAD AN
INTRODUCTORY BACKGROUND IN ELEMENTARY
NMR INTERPRETATIONS FROM TEXT OR LECTURE.
IT CONTAINS 2 NMR INTERPRETATIONS IN
WHICH I'II GO THROUGH A STEP-BY-STEP
INTERPRETATION, 2 INTERPRETATIONS AGAIN
IN A STEP-WISE MANNER, BUT WHICH ALLOW
YOU TO IDENTIFY THE COMPOUND AT ANY TIME,
AND 1 PROBLEM IN WHICH YOU MUST PREDICT
THE NMR SPECTRUM OF A GIVEN COMPOUND...
```

Figure 5. An example of an introductory statement for a lesson.

Within the main body of the program, a variety of strategies may be employed in the question-answer logic. In tutorial drill programs, for example, both correct and incorrect answers may be anticipated. In the case of the former, some positive response is always given. For the latter, appropriate tutorial responses pointing out the error are given (Figs. 6 and 7). For

```
WHAT IS THE NAME OF
  H2SO3
SULFUROUS
YOU OMITTED A WORD...ANSWER AGAIN,
PLEASE.
WHAT IS THE NAME OF
  H2SO3
SULFUROUS ACID
SWELL...
```

Figure 6. An example of response contingent feedback to the student.

```
WHAT IS THE NAME OF
  CA(NO2)2
TELL ME.
NO, TRY AGAIN, PLEASE...
CALCIUM NITRATE
WRONG SUFFIX...TRY AGAIN, PLEASE...
WHAT IS THE NAME OF
  CA(NO2)2
CALCIUM NITRITE
YOU BET...
```

Figure 7. An example of response contingent feedback to the student.

unanticipated incorrect answers, the format is generally to provide a strong tutorial hint for the first incorrect response, with the correct solution and/or problem set-up given following the second incorrect response (Fig. 8).

```
THE SIGNAL AT POSITION 2.40 DELTA IS
SPLIT BY WHAT NUMBER OF ADJACENT
PROTONS?
4
YOU ARE CLOSE...
REMEMBER, N PROTONS WILL SPLIT AN
NMR SIGNAL INTO N+1 PEAKS.
THE SIGNAL AT POSITION 2.40 DELTA
IS SPLIT BY WHAT NUMBER OF ADJACENT
PROTONS?
5
ACTUALLY, THERE ARE 4 PEAK(S), THERE-
FORE, 3 ADJACENT PROTON(S).
```

Figure 8. An example of tutorial responses following a student's first and second incorrect input.

In programs involving laboratory simulation a typical sequence includes 2-5 questions concerning the prerequisites for the experiment in terms of theory, design, and data analysis. This is followed by student manipulation of various experimental parameters, along with any required tutorial assistance, and collection of data. Generally, the student then signs-off, interprets his collected data and signs-on using another program that provides a step-by-step analysis of his interpretation and grades his performance (Fig. 9).

```
WELCOME BACK...

PLEASE ENTER YOUR ASSIGNED EXPERIMENT NUMBER? 3500
THANK YOU...
I'M VERY HAPPY TO PROVIDE YOU A CHECK OF YOUR CALCULATIONS.
THE FOLLOWING DATA IS ESSENTIAL FOR A CORRECT ANALYSIS OF
YOUR RESULTS.  PLEASE SUPPLY ME WITH...

*****MILLIMOLES OF I2 FROM PLOT INTERPOLATION = ? .30

*****MILLILITERS OF CCL4 = ? 50
FINE...THIS MEANS THAT IN 50 ML OF CCL4, THERE
ARE 0.3 MMOLES I2/LITER X 50 ML X LITER/1000 ML = 0.015 MMOLES I2


IN THAT THE REACTION PRODUCES 1 MOLE I2 FOR EACH MOLE OF
H202, 0.015 MMOLES I2 REPRESENTS 0.015 MMOLES H202...

*****VOLUME OF ORIGINAL UNKNOWN SOLUTION = ? 100
GOOD...THUS THERE IS A TOTAL OF
0.015 MILLIMOLES H202 X 100 = 1.5 MILLIMOLES
OF H202 in 100 ML OF THE UNKNOWN SOLUTION.

*****MOLECULAR WEIGHT (IN MG/MILLIMOLE) H202 = ? 34
O.K., GREAT... THUS THERE ARE
1.5 MILLIMOLES H202 X 34 MG H202/MILLIMOLE = 51 MG

***** 51 MG H202 ARE EQUIVALENT TO 0.051 GRAMS H202

SO, ALL WE NEED NOW IS......
*****WEIGHT (IN GRAMS) OF UNKNOWN SAMPLE = ? .8001
AND, ZOWIE, THE PERCENT OF H202 IN
BLEACH ACCORDING TO YOUR DATA IS
EQUAL TO 0.051 X 100 DIVIDED BY 0.8001 WHICH = 6.37 PERCENT
GOOD SHOW...JOLLY GOOD.  THE ACTUAL PERCENT OF
H202 IN YOUR SAMPLE IS 7.02 PERCENT...
COME AGAIN, FRIEND...
```

Figure 9. An example of dialog between the student and the computer lesson concerning the interpretation of experimental data collected by the student.

In the synthesis programs, matricies, as shown in Fig. 10, may be constructed of various reagents and products. A product to be synthesized is presented to the student, who then selects a starting material and suggests a step-by-step sequence of reactions to achieve the synthetic goal. In most of the synthesis lessons, we allow the student to follow whatever pathway he may choose for a given problem. However, the program does allow restarts should the student encounter a dead end, and tutorial assistance is provided should the student request it (Figs. 11 and 12). We also have synthesis programs that allow the student to work backward from the final product to a given starting material. These again are based upon a matrix of reagents and products.

At the conclusion of all programs an analysis of performance is presented to the student and, based upon an instructor-defined minimum level of achievement, either credit for the lesson is received by the student or else review work is prescribed. An example is shown in Fig. 13.

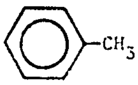
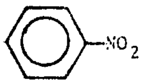
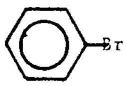
| Products ↓ (R) | Reagents (c) → $HNO_3/H_2SO_4$ (1) | $Br_2/Fe$ (2) | $KMnO_4$ (3) |
|---|---|---|---|
| (1)  | Reaction R=3 | Reaction R=4 | No Reaction |
| (2)  | Reaction R=5 | Reaction R=6 | Reaction R=7 |
| (3)  | Reaction (very slow) R=8 | No Reaction | No Reaction |
| (4)  | Reaction (very slow) R=0 | Reaction (very slow) R=10 | No Reaction |
| ⋮ | ⋮ | ⋮ | ⋮ |

Figure 10. Matrix construction for a computer-based lesson in electrophilic aromatic substitution synthesis.

```
          ORGANIC SYNTHESES

      FOR CREDIT, YOU MUST COMPLETE A MINIMUM OF
      5 SYNTHESES WITH A SCORE OF AT LEAST 80 %.

      NOTE...IF YOU SHOULD DESIRE YOUR SCORE AT ANYTIME
      DURING THE LESSON, ENTER 'SCORE'...

      YOU HAVE AVAILABLE THE FOLLOWING...

      STARTING MATERIALS...BENZENE OR TOLUENE.
      REAGENTS...HNO3/H2SO4 OR  BR2/FE  OR KMNO4.

      IN ADDITION TO THESE REAGENTS, YOU MAY ALSO REQUEST
      AID, RESTART, SKIP, ANSWER, OR STOP.

      NOW SYNTHESIZE...

      BR-C-CH
        /' '\
      HC.    .CH
        \. ./
      BR-C-C-C=O
              \
               OH

      STARTING MATERIALS?
----> TOLUENE

      REAGENT?
----> KMNO4

      THE MAJOR ORGANIC PRODUCT IS
        HC-CH     OH
        /' '\    /
      HC.    .C-C=O
        \. ./
        HC-CH

      REAGENT?
----> BR2/FE

      THE MAJOR ORGANIC PRODUCT IS
        HC-CH     OH
        /' '\    /
      HC.    .C-C=O
        \. ./
      BR-C-CH

      REAGENT?
----> AID
      -CH3 DIRECTS O-P, -COOH DIRECTS M...TRY NOW.

      REAGENT?
```

Figure 11. An example of a student's interaction with a computer-based lesson in electrophilic aromatic substitution synthesis. Note the total cost (LN = line connect charge, TM = computer charge).

```
COMPUTER, I WANT TO RESTART...
STARTING MATERIALS?
TOLUENE

REAGENT?
BR2/FE

THE MAJOR ORGANIC PRODUCT IS
    HC-CH
    /' '\
BR-C.   .C-CH3
    \. ./
    HC-CH

REAGENT?
BR2/FE

THE MAJOR ORGANIC PRODUCT IS
    HC-CH
    /' '\
BR-C.   .C-CH3
    \. ./
    HC-C-BR

REAGENT?
KMNO4

THE MAJOR ORGANIC PRODUCT IS
    HC-CH    OH
    /' '\   /
BR-C.   .C-C=O
    \. ./
    HC-C-BR
THAT'S THE ONE...
NOW SYNTHESIZE...

  HC-C-NO2
  /' '\
HC.   .CH
  \. ./
  HC-C-BR

STARTING MATERIALS?
STOP

I THANK YOU FOR YOUR INTERACTIVE PARTICIPATION, OLD COLD
HANDS...
BY THE WAY, MY FRIEND, I HAVE YOU RECORDED
FOR    0 CORRECT SYNTHESES OF    1 TRIED
WITHOUT ASKING FOR AID OR RESTART...
FOR A PERCENTAGE SCORE OF  0 ...
AND I'M CRAVING A MINIMUM OF 80 PERCENT
ON AT LEAST 5 SYNTHESES.  COME BACK AGAIN.
DO YOU WISH TO CONTINUE?       NO

LOGOUT
ACCOUNT-RUN  LN-MIN  LN-COST   TM-SEC  TM-COST
CBMJ010-258      12    $0.08    5.375    $0.38
```

Figure 12. An example of a student's interaction with a computer-based lesson in electrophilic aromatic substitution symthesis. Note the total cost (LN = line connect charge, TM = computer charge).

```
NOW THEN, PREDICT THE ORDER OF THE CHEMICAL SHIFTS
(UPFIELD → DOWNFIELD) BY LETTER...E.G., BCA...
———→ABCD
+++
OH, JOY, WILLIAM

TO SEE THE NMR SPECTRUM OF THIS COMPOUND,
EXAMINE FIG. 10

HERE'S AN ANALYSIS OF YOUR PERFORMANCE...
TOTAL QUESTIONS = 30 TOTAL CORRECT = 27
SCORE = 90.0
TOTAL PROBLEMS = 5 TOTAL CORRECT = 5
SCORE = 100.0

I'LL ACCEPT THAT AS SATISFACTORY...GOOD WORK...

    NMR MY FRIEND, WILLIAM
    BYE-BYE...

DO YOU WISH TO CONTINUE?   NO

CC:
———→LOGOUT
ACCOUNT-RUN  LN-MIN  LN-COST  TM-SEC  TM-COST
CBMJ010-082      29    $0.19   6.928    $0.50
```

Figure 13. An example of student performance analysis, concluding statements of the lesson, and cost data (LN = line connect charge, TM = computer charge).

## Evaluation

Evaluation of the program is a required, and indeed an exceedingly important, phase within the developmental process using the system approach. The method we use is one in which the class using the programs is designated as the experimental group and is compared with another class taught in the traditional manner by the same instructor. Classes taught by other instructors are also included for comparison. Variables such as background abilities, as measured by the SAT-verbal and SAT-mathematics scores and chemistry placement scores for each of the two groups are considered. Standard statistical routines such as regression analysis and analysis of variance are then used to test for any significant differences between the experimental and control groups in terms of performance on examinations, laboratory work, and the semester grades. Within the experimental group, student attitudes and opinions are also gathered through fairly detailed questionnaires and evaluated in regard to the programs and design of the course.

## Summary

We have detailed the process by which more than 100 successful interactive computer programs for use in general and organic chemistry have been prepared. The process is basically a version of the systems approach using an interactive debugging procedure. General programming strategies and evaluation schemes are discussed.

# THE USE OF MODULAR COMPUTER-BASED LESSONS IN A MODIFICATION OF THE CLASSICAL INTRODUCTORY COURSE IN ORGANIC CHEMISTRY

by

Philip L. Stotter* and George H. Culp*

## Introduction

The feasibility of using computer-based instructional techniques in undergraduate organic chemistry has been documented and described previously (1-6). The earlier studies at the University of Texas at Austin using programs developed by Dr. G. H. Culp with the cooperation of Professors L. B. Rodewald, P. L. Stotter, and J. C. Gilbert, were conducted under experimental conditions in which randomly selected groups were given access to computer-based lessons and compared in terms of performance and attitudes with a control group from the same class. In each case the groups were relatively small in number and, with the exception of access to supplemental computer-based lessons, the course was conducted in the traditional method of three 50-minute lectures and one 4-hour laboratory per week. We present here a description of the first major experiment in which the conventional introductory organic course was extensively modified, based on these earlier studies, to include computer-based instructional techniques within the curriculum.

## Course Design

At the University of Texas, Austin, introductory organic chemistry, Chemistry 818 (designed primarily for majors in chemistry, pharmacy, and chemical engineering), is taught as a two semester 8-credit-hour course. The course structure normally includes three 50-minute lectures (or two 75-minute lectures) and one four-hour laboratory, weekly. One section of the first semester of this course taught by P. L. Stotter in Fall, 1972, was designated as the experimental course. The text used was "Organic Chemistry" by Morrison and Boyd (2nd edition). Of the 106 students originally enrolled at the beginning of the semester, 73 students completed the course (the balance received grade designations of Q, $F_{abs.}$, and X, as shown in Table II).

The design of the experimental course differed from that of the traditional course described above in several respects. The number of formal lecture sessions was decreased from three to two 50-minute meetings per week. The originally scheduled meeting time reserved for the standard

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third formal lecture was used as an optional discussion period. Twenty-one computer-based lessons (average length approximately 35 minutes each (Table I) were assigned as a required part of the course.* Students

Table I

Assigned Computer Lessons for Experimental Section of Chemistry 818a

| | Name | Area |
|---|---|---|
| 1. | OCH16 | Valence Bonding and Organic Compounds |
| 2. | OCH34 | Classes of Organic Compounds |
| 3. | OCH1 | Alkane Nomenclature |
| 4. | OCH22 | Separation via Extraction |
| 5. | OCH18 | Chlorination of Propane |
| 6. | OCH24 | Basics of Stereochemistry |
| 7. | OCH2 | Alkene Nomenclature |
| 8. | OCH14 | Dehydration of 2-Methylcyclohexanol |
| 9. | OCH10 | Preparations and Reactions of Alkenes |
| 10. | OCH31 | Reporting Laboratory Results |
| 11. | OCH17 | Elementary Alkene-related Syntheses |
| 12. | OCH14 | Arene Nomenclature |
| 13. | OCH19 | Mechanism of Electrophilic Aromatic Substitution; Orientation; Reactivity |
| 14. | OCH11 | Preparations and Reactions of Arenes |
| 15. | OCH6 | Elementary Aromatic Syntheses |
| 16. | OCH7 | Aromatic Syntheses |
| 17. | OCH3 | Alcohol, Aldehyde, Ketone Nomenclature |
| 18. | OCH12 | Preparations and Reactions of Alcohols |
| 19. | OCH29 | Preparations and Reactions of Phenols |
| 20. | OCH32 | Elementary NMR Interpretations |
| 21. | OCH33 | Elementary IR Interpretations |

scheduled their computer interactions at times convenient to their own schedules and used standard teletype consoles. The lessons were written in CLIC (Conversational Language for Instruction and Computing), an interactive computer language developed by personnel of the University of Texas Computation Center and designed for the University of Texas CDC 6400-6600 system. A minimum level of achievement of 85 percent was established for most of the lessons. Until this level was attained, the student received no credit for the lesson interaction, but was allowed to repeat the interaction as many times as he wished without penalty until he demonstrated a satisfactory performance. The regularly assigned laboratory periods were not modified.

*A priori*, this modified course design was predicted on the now-documented rationale for using computer-based instructional techniques, *i.e.*, there are certain aspects within the learning process that may be treated more effectively by computer-based tutorial interactions, with the potential of providing self-paced, individualized instruction, than by classroom-structured human interactions. In this regard, the computer lessons emphasized areas that require drill--often patient, tutorial drill--as well as chemical logic and simulated experiment and reaction applications (in which the student may control several experimental parameters without the constraints of available time, equipment, and space). Furthermore, this design allowed the instructor to be freed from much of the routine instruction inherent within the traditional approach,

*A brief abstract including performance objectives for each lesson is available from the authors.

and the two weekly lectures were devoted almost entirely to more-generalized theoretical concepts of bonding, structure, stereochemistry, and reaction mechanism.

Three hour exams totaling 500 points and a final exam totaling 650 points were given. Points were also assigned to the semester laboratory grade (A=400 to D=100) and 150 points were credited to students who had successfully completed at least 20 of the computer lessons. Ten points were deducted for each lesson not completed. The course grade was contingent upon the total number of points attained.

Pedagogical Rationale

We have, for some time, believed that traditional organic chemistry instruction fails to utilize its available instructional resources very efficiently. In the past, our traditional classroom presentation has tended more towards training of undergraduate students, encouraging their passivity, than towards educating them. "Educating them" implies to the authors the necessity of allowing and encouraging student acceptance of an active, aggressive student role in defining his own learning experience. However, time makes such an approach difficult. Traditionally, as instructors of introductory organic chemistry, we have assigned comprehensive texts and then, too often, have found it necessary to spend most of our lecture time digesting and condensing the textual material. And we have, the authors believe, with disastrous results encouraged our students to expect such presentation, *i.e.*, we have encouraged them to believe that their role should be, and will be, a passive one and that any demand for more active student participation is unreasonable. The more comfortable and effortless we make his passive training experience, the better the organic student believes the quality of his instruction to be. Accordingly, a commonly heard student evaluation of chemistry lecturers is, "That instructor is really good; his lectures are so clear, logical, and comprehensive that I don't have to use the text at all".

A more efficient use of text and lecturer seemed to us to be one where each complements the other. For five years, one of us (PLS) has attempted to convince his own undergraduate students that their text must be their primary source of information, that lectures would supplement and clarify, and would attempt to demonstrate alternate logical constructs and relationships in addition to those well-defined by the text. He has further suggested that completion of assigned reading schedules, problems, etc., was an essential learning responsibility (whether or not all the content detail were discussed in lecture). Unfortunately, his students have not been willing to accept such responsibility. He found he could not depend on his students to work through material unless it was well discussed in lecture. And, further, he found they were unable (or unwilling) to use a detailed discussion of one topic as a model for logical thinking about related topics (unless specific demonstrations of how the model should be applied were included in lecture). Unfortunately, two semesters of lectures is insufficient for such detailed discussion of all the content of a comprehensive, thousand-plus page text.

Several alternatives seemed possible. Assign a simpler, less detailed text for "overview" and complement it with a lecture series of comprehensive detail. Or assign a comprehensive, detailed text (as is traditional) and complement it with selected, but deeply-developed, examples of generalized theoretical "overview", and with individualized tutorial drill to reinforce the text. Although it seems a more viable choice for comprehensive understanding of organic chemistry, the latter possibility, however, requires that students be convinced that their role is an active learning one, that lecture presentation will not fulfill the role of elementary training, and that the responsibility of correlating different, but related, information from various sources is their own.

In this regard, the division of lecture presentation into separate and disparate sections, one section to provide elementary drill and practice and one to demonstrate in-depth development of new logical relationships, seemed constructive. This fragmentation, we hoped, would necessitate active participation from each student in accepting responsibility for his own individual and highly personal synthesis of information from all disparate instructional sources. And, further, computer-based techniques might well be incorporated, not only to provide efficient, individualized tutorial drill, but to accentuate this division of lecture material; to the student involved in this learning experience, the computer and lecturer would obviously be disparate information sources in terms of content, style, purpose, and physical presence. We hoped that, when faced with the necessity of correlating information derived from these various cognitive information sources, a student who "put together" a coherent, meaningful entity from textbook, lectures, and computer lessons would have learned organic chemistry via a personally meaningful experience.

Accordingly, the experimental course was designed to include the following: assigned readings and study problems in the text covering chapters 1 through 12, 14 through 17, 25, 26, 28, 35, and parts of 13 and 21; the computer lessons indicated in Table I which were intended to reinforce specific areas of objective detail covered by the text; two 50-minute lectures per week which used structure, stereochemistry, and mechanism as their organizational focus, to provide contrast with the functional group organization of the text and computer lessons.

It was made clear that objective detail (such as simple reactions) was to be learned during the semester from the text source, aided by computer lessons; that some of this detail would be incorporated into the formal lectures, but that the instructor had no intention of reviewing all the detail of the text; and, finally, that such objective detail not covered in computer lessons was nonetheless each student's responsibility. During what would have been the third formal lecture hour of a traditionally constructed course, an optional and informal question-answer-discussion period was scheduled to handle problems and difficulties students might encounter in their "auto-instruction". Accordingly, the lecturer was often requested to give mini-lectures concerning specific detail or covering specific objective topics during this informal meeting.

## Evaluation

In Table II is a comparison of student background abilities and performances (as indicated by SAT mathematics and verbal scores and by grade

Table II

Semester Grade Distribution for Chemistry 818a

| Year | Lecturer | Grades (%) A | B | C | D | F | $F^a$ (abs) | $Q^b$ | $X^c$ | SAT (Verbal) | SAT (Math) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fall 72[d] | X | 11 | 16 | 23 | 15 | 4 | 4 | 25 | 2[e] | 549 | 629 |
| Spring 70 | X | 12 | 13 | 16 | 20 | 9 | 0 | 16 | 13[f] | 558 | 639 |
| Fall 72 | Y | 9 | 22 | 20 | 15 | 13 | 0 | 20 | 0 | - | - |
| Fall 70 | Z | 7 | 17 | 22 | 12 | 16 | 13 | 14 | 0 | - | - |

[a] Absent from class and final exam, but failed to drop the course officially

[b] Dropped the course without penalty (work satisfactory at time of drop)

[c] Incomplete grade assigned

[d] Experimental course

[e] Students are actively engaged in completing small amount of remaining course work (course work already completed is passing).

[f] Small number of these students subsequently completed course satisfactorily; most allowed grade of X to lapse into F after four months.

distribution) for the experimental class and a more traditional class taught by the same instructor 30 months earlier. It should be noted that the earlier class is not a directly appropriate control because of two characteristics: first, some of its students had access to a limited number of computer-based lessons; and, second, it was taught in the spring semester and, consequently, contained a large number of repeating students. For this reason, the grade distributions were also compared with two traditional courses taught by different instructors during the same (or closely related) time periods. In addition, anonymous attitudes and opinions were formally solicited from students in the experimental class.

## Results and Discussion

Student Performance. Students apparently accepted the fact that materials not discussed in computer lessons or lecture but assigned in the reading (*e.g.*, much of the objective detail concerning acetylene reactions) were nonetheless their responsibility, since their examination performances showed quite satisfactory grasp of such objective detail.

The distribution of course grades and other pertinent data for the four classes are shown in Table II. In terms of achievement, the data suggest an equivalence of background ability for the two classes with the same instructor, (X), and, most important, that the experimental approach is on a level equal to, or better than, the traditional approach. In this comparison, improvement is indicated in the middle and lower achievement groups for the experimental class, supporting the findings of the earlier studies in organic chemistry that show these groups can most benefit from the individualized, tutorial-drill instruction provided by the computer-based lessons. Comparison of the experimental class with the two traditional classes taught by different instructors indicates no significant differences in the distribution of passing grades. However, it is interesting to note the small percentage of failing grades and the relatively high percentage of drops without penalty for the experimental course. We believe these data suggest that in the experimental course each student was better able to determine--early in the semester--whether he would devote the time sufficient to complete the course successfully and, if not, drop without penalty while his work was still at a satisfactory level.

Perhaps the most viable statistical evidence for evaluating the learning effectiveness of students in the experimental course, an indication of their performance in subsequent organic chemistry courses, is not yet available. However, preliminary data, such as examination scores, indicate that students who transferred from the experimental course to a more traditional second semester course are performing satisfactorily (as judged by comparison of current exam grades with the final course grades they earned in the experimental course). One other phenomenon of interest is the performance of students from the experimental course who are now repeating the first semester with another instructor in a section using traditional presentation. (In the experimental section these students received grades of D, F, $F_{abs}$', and Q which are not satisfactory prerequisites for Chemistry 818b.) It is not yet possible to give an accurate description of their current progress; but, again, preliminary examination data suggest they may be performing at a success level higher than that normally expected of typical repeaters.

Three of the computer lessons were directly related to the laboratory portion of the course: one to gathering, interpreting, and reporting laboratory results; and two to simulated experiments prior to related, real experiments in the laboratory. Table III shows a general improvement in laboratory performance for the experimental class. However, the instructor

Table III

Laboratory Grade Distribution for Chemistry 818a[a]

| Year | Lecturer[b] | Grades (%) A | B | C | D | F |
|---|---|---|---|---|---|---|
| Fall 72[c] | X | 35 | 44 | 21 | 0 | 0 |
| Spring 70 | X | 23 | 40 | 29 | 8 | 0 |
| Fall 72 | Y | 29 | 35 | 29 | 7 | 0 |
| Fall 70 | Z | 22 | 34 | 42 | 1 | 1 |

[a]For students completing the course

[b]Lecturer conducted formal lecture part of course; laboratory instruction and grading performed by other personnel

[c]Experimental course

finds it difficult to believe that three computer-based laboratory lessons were, alone, responsible for the unusually high laboratory performance; and this feeling is shared by the students involved. Perhaps a more appropriate explanation for the trend can be found in the greater degree of student self-reliance and independence necessitated by the overall experimental course structure. If these qualities carried over into his laboratory work, we might well expect such a student to come to laboratory better prepared and more likely to accept initiative and responsibility in conducting his own experiments. That the data is meaningful is best indicated by two facts: in laboratory sections, students of the experimental course were randomly mixed with students of a traditional course; and, at the University of Texas, introductory organic laboratory (instruction and grading) is normally carried out by personnel other than the formal lecturers of the course. Considering that the laboratory grade is based primarily upon experimental work, laboratory reports of real experiments performed, and performance on quizzes related to technique and/or theory, the grade distribution suggests that the experimental course design and its use of computer-based tutorial are, at the least, the equivalent of traditional instruction.

Student Attitudes Concerning Use of Computer-based Lessons. Anonymous student opinion regarding the design of the course and, specifically, the use of computer-based techniques as an essential element is shown in Tables IV and VI. In Table IV, positive attitudes are given by a majority of the students on four of five items, particularly those relating to assistance in learning provided by the computer lessons. These attitudes were verified in a follow-up evaluation 8 weeks after the semester ended. Emotional extremes at both ends of the spectrum seem less apparent in the follow-up study. The one initially negative response (an apparently bimodal distribution of answers to Question 2 concerning the equivalency of time required for one-lecture vs one-computer-based-lesson) is a legitimate response supported by the actual computed time used by students to complete average lessons successfully. (See Time Required below). However, the longer time period required to complete a computer-based lesson is probably a function of the minimum achievement level defined for each lesson (85% satisfactory performance), and of the fact that many students came unprepared to their first interaction with each lesson (i.e., many students used the computer tutorial as introductory work prior to text study, and, then, subsequently repeated the lesson after completing the assigned study materials). This phenomenon is common in most traditional lecture courses. Students often use the lecture as an introduction to the text, even when assigned reading in the text is supposed to precede the lecture. What instructors rarely have an opportunity to do, however, is require students to sit through the lecture a second time for effective learning after they have completed the reading. Although, originally, students were perhaps somewhat justifiably angry about the extensive time demands, they have apparently begun to recognize their own responsibility for the extra time required when they chose to use the computer lessons as introductions to the text. In the follow-up attitude study, the bimodal distribution observed for responses to Question 2 reflects a somewhat positive attitude change. Of the three groups examined,

Table IV

Student Attitudes Concerning Computer-based Lessons[a]

| Item | Opinion (%)[b] Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree |
|---|---|---|---|---|---|
| 1. Computer techniques are good study aids | 3 / 2(0-0-9) | 3 / 5(4-8-9) | 2 / 2(0-0-9) | 54 / 57(59-46-64) | 37 / 33(37-46-9) |
| 2. The time required for these lessons was the equivalent of the traditional 3rd formal lecture | 17 / 15(7-23-27) | 44 / 29(26-54-9) | 12 / 8(11-0-9) | 23 / 45(56-15-55) | 3 / 2(0-8-0) |
| 3. The lessons have helped me learn | 3 / 0(0-0-0) | 2 / 2(0-9-0) | 9 / 13(7-9-36) | 53 / 57(67-46-45) | 33 / 27(26-38-18) |
| 4. I have enjoyed the lessons | 11 / 5(0-9-18) | 5 / 8(7-15-0) | 22 / 21(26-23-9) | 36 / 55(56-38-73) | 26 / 10(11-15-0) |
| 5. I would use this type of study aid in other courses if it were available | 7 / 4(0-0-18) | 5 / 0(0-0-0) | 28 / 13(15-23-0) | 40 / 68(70-62-73) | 19 / 14(15-15-9) |

[a] Voluntary anonymous responses were solicited from students immediately prior to final examination (56 responses), and eight weeks after end of course (51 responses). Note that there may be some variation based on difference in students who chose to respond.

[b] % opinions tabulated as shown: $\frac{{}^{1}n}{{}^{2}n(S_{SKB}-K_{SB}-B_{SA})}$

where ${}^{1}n$ = % of 56 voluntary responses received prior to examination

${}^{2}n$ = % of 51 voluntary responses received 8 weeks after end of course

${}^{2}n$ is further broken down into

$S_{SKB}$ % of total responses from experimental group taking second half of course (818b) with instructor of experimental course

$K_{SB}$ % of total responses from experimental group taking second half of course (818b) with another instructor

$B_{SA}$ % of total responses from experimental group repeating course (818a) with another instructor

one group of students who completed the experimental course with a grade of C or better and who are now enrolled in Chemistry 818b with the instructor of the experimental course gave a generally positive response; students from the experimental course with comparable grades who transferred to a traditional Chemistry 818b section responded more negatively; and, perhaps most interesting, the group now repeating the introductory course in a traditional section is strongly divided in their response, with a significant majority actually agreeing to the time equivalency. It should be noted that the majority of Chemistry 818b transfer students cited schedule preferences and conflicts as primary reasons for their transfer, although some did indicate that they expected less time and effort would be required by a more traditional class. Table V reflects this phenomenon. When asked in the follow-up questionnaire to respond to the similarity of grade distributions for the

Table V

Voluntary Anonymous Responses to Follow-up Questionnaire*

| Item | $S_{SKB}$ | $K_{SB}$ | $B_{SA}$ |
|---|---|---|---|
| Attitude towards grade distribution (%) | | | |
| The grade distributions for all Chemistry 818a courses taught in Fall of 1972 were about the same. Is this: | | | |
| About what you expected? | 54 | 31 | 55 |
| A surprise to you? | 13 | 31 | 27 |
| Of little concern to your expectations? | 33 | 38 | 18 |
| System problems (%) | | | |
| How many problems did you have with the Taurus System? | | | |
| Many | 4 | 8 | 18 |
| Occasionally | 85 | 92 | 73 |
| None | 11 | 0 | 9 |
| Program problems (%) | | | |
| How many problems did you have with errors in the computer lessons? | | | |
| Many | 7 | 0 | 9 |
| Occasionally | 85 | 85 | 82 |
| None | 7 | 15 | 9 |

*For an interpretation of notations $S_{SKB}$, $K_{SB}$, and $B_{SA}$ please see note b, Table IV.

the experimental and traditional sections, a substantial part of the transfer group showed surprise.

In all three groups, students indicated a preference for the areas of nomenclature, reactions, synthesis, and spectral interpretation as being well-suited for computer-based lessons.

In the original and follow up-evaluations*, the three groups gave essentially identical responses in listing advantages of the computer-based lessons. They were overwhelmingly in support of the individual, self-paced, tutorial drill approach which these lessons allowed; and, in general, they

*Student comments describing their general feelings about computer-based instruction in organic chemistry were also solicited (as part of the questionnaires). The authors interpreted these comments as an indication of the successful use of computer-based instruction in the experimental course. However, additional evaluation of these responses was deemed appropriate; accordingly, the authors requested that Professor David W. Brooks of Texas A & M University evaluate these student comments, utilizing the methods he described in his contribution to the Symposium on Student Evaluation of Chemistry Courses and Professors via Questionnaires, 165th ACS National Meeting, Dallas, Texas. Professor Brooks concluded that the student responses constituted a positive and meaningful evaluation of the instructional role played by the computer-based lessons in the experimental course.

repeatedly praised the active student participation level encouraged by the lessons. In this regard, the instructor noted an unusual level of positive excitement and anticipation among the students throughout much of the semester which sharply contrasts with the sense of oppression commonly encountered among organic students. It is possible that it was only the novelty of a new, "educational toy" which buoyed their interest and excitement, but the observable effect made the classroom significantly more pleasant a place in which to lecture.

Disadvantages of computer-based instruction that were cited included the time required to complete the computer-based lessons successfully, difficulties in scheduling extra interactions with difficult lessons (a shortage of teletype terminals during popular hours), certain idiosyncrasies within individual lessons that failed to recognize an acceptable correct response, and problems with the computer system hardware that necessitated the postponement of scheduled interactions with the lessons (see, also, Table V).

Student Attitudes Concerning the Overall Approach Used in the Experimental Course. Examination of Tables VI and VII illustrates that average responses solicited just prior to the final examination in the experimental course and average responses some 8 weeks later show general approval of the course design and the computer-based lessons. More interesting is the fact that the collection of small trends is largely in the direction of greater approval with distance.

However, it should be noted that while suggesting the experimental course approach seemed, cognitively, reasonable and justifiable (Tables VI and VII), many students were emotionally distressed by the extensive time and active learning efforts required of them. Their rancor was directed largely at the instructor (Table VII and individual comments which accompanied the formal university evaluation), although this emotional response, too, appears to be lessening with distance.

Time Required. Table VIII contains data concerning the computer time required and cost figures for the semester. A total of 2,082 jobs requiring 1,490 computer contact hours for the students occurred in the semester. On the average, about 1.6 interactions were required per lesson per student for a successful completion. This is the equivalent of about 43 minutes per job, and, assuming that one job represents one lesson, about 70 minutes for a successfully completed lesson.

Costs. Computer costs are based upon a rate of $260.00 per TM hour (a combination of central processing (CP) and peripheral processing (PP) time) and a line connect charge that was originally $0.50 per hour but was reduced in the 10th week of the semester to $0.40 per hour. A total of 7.21 TM hours costing $1875.10 and $667.65 for connect time were required for the 2,082 jobs. These figures correspond to approximately $1.71 per student terminal hour or $1.99 total cost per successfully completed lesson per student. It is very important to note, however, that a rate of only $26.00 per TM hour is charged at the departmental level within the University

Table VI

Additional Questions for Formal University Student Evaluation (Anonymous and Voluntary) of Experimental Course and Instructor

For Following Questions

| Answer: | Definitely Yes | Yes | Uncertain | No | Definitely No |
|---|---|---|---|---|---|
| | +2 | +1 | 0 | -1 | -2 |

Did the use of computer-based instruction help you discover and use your own pace for learning organic chemistry?

$(\bar{X})^a$ = .4[.7](.8)

Do two formal lectures per week plus regular computer-based lessons seem to provide sufficient explanation of subject matter for a self-paced introductory course in organic chemistry?

$(\bar{X})$ = -.7[-.5](-.2)

Is it fair to ask students to teach themselves organic chemistry from a selected textbook aided by formal lectures and computer-based lessons?

$(\bar{X})$ = .2[.5](.8)

If this course had been composed of three formal lessons per week and <u>optional</u> computer-based lessons, would you have devoted as much time to studying the computer-based lessons as you did this semester?

$(\bar{X})$ = .4[.2](.2)

Did you find working on the computer-based lessons an enjoyable way to learn organic chemistry?

$(\bar{X})$ = .6[.8](1.0)

Do you think it is accurate to say that the textbook presents an introduction to organic chemistry organized descriptively according to functional groups, while the formal lectures seem to present a broader, more theoretical organization according to organic structure and reaction mechanism?

$(\bar{X})$ = .9[.8](1.0)

Should a combination of computer-based instruction and formal lectures (such as used this semester) be used in future courses to help students learn organic chemistry?

$(\bar{X})$ = .9[1.0](1.2)

---

[a] Average responses indicated as $^1n[^2n](^3n)$

where $^1n$ shows average of 61 responses obtained immediately prior to final examination

$^2n$ shows average of 52 responses obtained 8 weeks later both from students currently enrolled in second half of organic chemistry (818b) and from students repeating first half of organic chemistry

$^3n$ shows average of 37 responses of students currently enrolled in 818b only

---

For Following Questions

| Answer: | most of the time | a good part of the time | some of the time | a small part of the time | never |
|---|---|---|---|---|---|
| | +2 | +1 | 0 | -1 | -2 |

Have you resented being part of this experiment which is trying to define new ways of presenting subject matter in an introductory organic chemistry course?

$(\bar{X})$ = -1.0[-1.2](-1.4)

Were you able to correlate the two different organizational approaches used in the text and in formal lectures?

$(\bar{X})$ = .4[.2](.5)

If you think back over the feelings you had while completing the required computer-based lessons, do you believe you were usually trying to learn and understand the content of each lesson (instead of just trying to get through one more assignment)?

$(\bar{X})$ = .5[.6](.8)

Table VII

ANONYMOUS STUDENT RESPONSES TO PERTINENT QUESTIONS FROM FORMAL UNIVERSITY EVALUATION*

A comparison of average responses ($\bar{X}$) of students in experimental course and in traditional course taught by same instructor 30 months earlier

| | Spring 1970 | | Fall 1972 | | |
|---|---|---|---|---|---|
| scale: Def. Yes +2 / Yes +1 / Neutral 0 / No -1 / Def. No -2 | Control | Limited CAI access | Before final exam | Eight week follow-up ($S_{SKB}+K_{SB}+B_{SA}$) | ($S_{SKB}+K_{SB}$) |
| expected to enjoy course | .6 | 1.1 | .6 | .6 | .7 |
| instructor well-prepared | 1.0 | 1.4 | .9 | 1.0 | 1.2 |
| well-paced course | -1.0 | -1.4 | -.5 | -.1 | 0 |
| adequate text | 1.2 | 1.3 | 1.1 | 1.0 | 1.4 |
| expected course to be of value | | | 1.1 | 1.2 | 1.4 |
| found course of value to date | | | .9 | .8 | 1.2 |
| scale: One of best +2 / Above ave. +1 / Ave. 0 / Below ave. -1 / Far below ave. -2 | | | | | |
| comparison with other instructors | 1.0 | .7 | .2 | .4 | .6 |
| comparison with other courses | .8 | .7 | .6 | .7 | .9 |
| scale: Far more than expected +2 / More than expected +1 / Expected 0 / Less than expected -1 / Far less than expected -2 | | | | | |
| comparison of course with original expectations | .5 | .3 | .2 | .1 | .3 |
| scale: Well above ave. +2 / Above ave. +1 / Ave. 0 / Below ave. -1 / Well below ave. -2 | | | | | |
| student effort in course | 1.2 | 1.3 | 1.4 | 1.3 | 1.4 |

*For an interpretation of notations $S_{SKB}$, $K_{SB}$, and $B_{SA}$ see Table VIII.

Table VIII

Time Required and Cost of Interactions

Number of jobs (sign-ons) run: 2,082

Hours of computer connect time: 1,489.89

Computer TM* hours: 7.21

Computer TM charge: $1,875.10

Computer connect time charge: $667.65

Hours per successfully completed module: 1.17 (70 minutes)

Cost per successfully completed module: $1.99

Cost per student-terminal hour: $1.71

*TM hour includes central processing time and peripheral processing time.

system. Had funds for this project come directly from the Chemistry Department teaching budget (rather than a research account), the total cost would have been about $0.58 per student terminal hour.

Instructor's Evaluation. (The authors believe it is most appropriate for P.L.S. to comment directly in this phase of the evaluation.) I feel the experimental approach was a success in many respects. Students demonstrated active, inquisitive effort and kept to a minimum the usual complaints concerning the unreasonable demands organic chemistry places on its students. I am, for the first time in five years, satisfied that the grades I assigned at the conclusion of an undergraduate chemistry course are, for the most part, an accurate and well-deserved representation of what the students have learned. I felt useful in the classroom. Rather than feeling limited by the necessity of simply providing a condensed version of some text, I felt able to engage in teaching--that is, in providing a thought-provoking and informative environment in which students can choose to learn.

However, when faced with the difficult task of deleting about one-third of my normal classroom objective content so that the computer lessons might deal with this material via one-to-one tutorial methodology, I recognized that I must in the past have been lecturing at a phenomenal rate, covering information at a pace so rapid that information could be taken down but not simultaneously processed by the students. This realization convinces me that what students of our organic course have been saying for years is true; we demand an excessive amount of work from them (even in traditional training courses). Both my students and I strongly believe that it would be appropriate to extend introductory organic chemistry to three semesters (with 9 hours total credit) or to offer in the first semester of a two-semester course a modification of the experimental course in which three lectures per week, one four-hour laboratory, and computer-based lessons (equivalent to a fourth lecture) would be included for a total of 5 credit hours.

Finally, a word about completely self-paced instruction for organic chemistry. From my experiences last semester, I believe that the nature and multi-dimensional complexity of the content of introductory organic chemistry do not allow for further extensive modularization. Units of study, such as chapters in a text, can be well defined with appropriately described goals and methodology. But organic's unique problem is not the need for further modularization; it is, rather, the opposite. It is the necessary and difficult task of correlating and synthesizing these many units into a single construct, of recognizing a multitude of different interconnections between any collection of individual units, and of solidly developing a complex structural interdependence of all units to support the total, internally consistent structural entity which we call organic chemistry. All this suggests to me is that no simple introductory organic course can be fashioned which will allow an average student to achieve completely self-determined and self-paced learning in the field within a reasonable time period. I believe that live interaction with a lecturer and with a scheduled series of lectures is probably a quite necessary learning aspect, if students are to complete an introduction to organic chemistry in two or three semesters. But I am certain that active student participation in the learning process, including as large a degree of self-pacing as is possible, can substantially improve the learning environment. In this regard, modularized computer-based tutorial lessons appear to be an effective, perhaps essential, adjunct to chemical instruction. For, after five years of unsuccessful attempts to convince my undergraduates that an organic text should be their primary information source, I can call your attention to Table IX with some satisfaction.

Table IX

Student Ranking of Contribution to Learning of Organic Chemistry

Students were asked to:
Rank the following in the order which you feel would most contribute to learning organic chemistry. Rank the most important as No. 1 and the least important as No. 5.

____ Textbook
____ Formal lectures
____ Question and answer discussion period
____ Laboratory (including laboratory lecture)
____ Computer-based lessons

Averaging their responses for each item gave the following order (questionnaire administered before final examination):

Text
Computer
Lecture
Lab
Q-A Period

($\overline{X}$) average ranking on anonymous follow-up questionnaire*

| $S_{SKB}$ | $K_{SB}$ | $K_{KB}$ (control) | $B_{SA}$ |
|---|---|---|---|
| 1. 37-text | 1. 46-text | 1. 29-lecture | 1. 36-text |
| 2. 04-lecture | 1. 92-lecture | 2. 13-text | 2. 27-lecture |
| 3. 11-computer | 3. S8-computer | 3. 16-Q-A period | 3. 27-computer |
| 4. 00-lab | 3. 85-Q-A period | 3. 9S-lab | 4. 00-lab |
| 4. 44-Q-A period | 4. 27-lab | 4. 32-computer | 4. 09-Q-A period |

*$S_{SKB}$ = students from experimental group now taking second half of course (818b) with instructor of experimental course

$K_{SB}$ = students from experimental group now taking second half of course (818b) with another instructor

$K_{KB}$ = students with no exposure to experimental course, now enrolled in second semester (818b) with another instructor

$B_{SA}$ = students from experimental group now repeating course (818a) with another instructor

## Summary

An experimental course in first semester undergraduate organic chemistry was designed to incorporate now-documented computer-based instructional techniques. The design included required computer-based lessons that provided tutorial drill and practice and simulated experiment and reaction applications. Most of the lessons required a minimum achievement level of 85 percent for credit. Since much of the routine instruction was accomplished within the computer lessons, it was possible to reduce the number of formal lectures per week from three to two, but simultaneously to increase the amount of time and detail devoted to theoretical concepts such as bonding, structure, stereochemistry, and reaction mechanism.

Divison of lecture responsibility between formal lecturer and computer-based lessons in the experimental approach appears to have developed a greater-than-normal amount of self-reliance, independence, and responsibility from students; the phenomenon is exhibited in student evaluations by the unusually high importance they assigned the text as a primary information source.

Evaluation of the experimental course by comparison with three courses taught by more-traditional methods, including one taught by the instructor of the experimental course, indicated the experimental course approach is, academically, equal to, or better than, traditional methods. Positive student attitudes and opinions concerning use of computer-based lessons as an essential and pedagogically valuable part of the experimental course were received.

Finally, the experimental course and its evaluation have convinced the authors of the following: that students can be encouraged to take a more responsible and aggressively active part in their own organic chemical instruction; and further, that although comprehensive understanding of introductory organic chemistry can, seemingly, be developed in two semesters (by either the experimental or traditional approaches), both approaches place unusually high time demands on students for satisfactory progress.

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COMPUTER ASSISTED SELF-PACED INSTRUCTION

by

Leslie N. Davis*, Jak Eskinazi* and Daniel J. Macero*

## INTRODUCTION

A series of highly interactive computer teaching programs for drilling, tutoring, and supplementing laboratory work has been developed for use in undergraduate chemistry courses at Syracuse University. Our programs are adaptable to individual student requirements both in content and pacing, either automatically through decisions the computer makes based on student input, or under user-control through student decisions to review, repeat, or skip a subject area. Some of the programs are capable of considerable detailed analyses of student input (e.g. correcting spelling errors or helping derive equations) aside from dealing with the basic subject matter. The programs include: A Symbols of the Elements Drill which automatically biases itself to drill the user most frequently on the material he is least familiar with; a Tutorial Program in pH Concepts and Calculations which can take the user through as much of an 18 lesson course on exponents and logarithms as he requires; a package of programs in Electronics, Spectroscopy, and Gas Chromatography designed to supplement an upper level course in Chemical Instrumentation; and a Computer Enhanced Laboratory Determination of Absolute Zero which involves the students in actual data-taking and handling of apparatus in the laboratory prior to use of the computer to simulate the experiment in complete detail and with the capability of varying experimental parameters beyond the physical limits of the laboratory.

## CAIR PRINCIPLES FOR PROGRAM DESIGN

Well designed programs for self-paced instruction will adhere closely to the principles we have established for CAIR in program design (1):

Consistency
The detailed structure of the program should further design goals systematically, yet each experience of program use should be unique for the user.

Accessibility
Software and hardware must be readily available to CAI users. The program should not presume knowledge or skills (i.e. typing, computer languages) irrelevant to the immediate subject matter of the program.

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Interactivity

The program must be flexible and adaptable to varying use needs. It must be, in brief, self-paced. The user should have input, other than his responses, as to the direction the program will take.

Real-life Conformity

Program operation should not be limited by constraints inherent in the computing system. Chemical equations, for example, should be displayed in the standard form the student sees in his textbooks, not in an unusual style limited by the computer output.

A DRILL PROGRAM

There are three types of drill methods of which the computer is capable, namely, simple deal, random access, and biased random access drill (BRAD). In simple deal, the computer reads down a list of the material to be drilled in fixed order. Needless to say, this makes inefficient use of the computer's potential and will not be discussed further. A random access drill employs the computer's ability to present drill material in a nonrepetitive fashion which reinforces association of data couples rather than a fixed presentation pattern. The efficiency of random access drill is exceeded only by that of the BRAD approach in which case the data base shifts or biases itself to test most often those data couples for which the user has demonstrated least familiarity by one or more misses on previous trials. The BRAD approach is inherently self-pacing and offers the highest potential for efficient mastery of the drilled material.

Our program ELEMENTS (1) is a BRAD type program which drills the names and symbols of the chemical elements. It is intended for use by beginning chemistry students who wish to rapidly master this important aspect of chemical shorthand. We also use it in a chemistry course for nonscience majors as an introductory experience with the computer.

Self-pacing in ELEMENTS is carried beyond its BRAD characteristic. Indeed, the self-pacing nature of any program is directly related to the depth of interactivity possible between the computer and the user. In ELEMENTS the user determines all the major operational parameters of the program, and he may change these at any time during program execution. These include fixing the data base contents (ranging from the 20 most common elements to the entire periodic table in steps of about 20 elements), the number of trials before the answer is provided, and whether the drill will be on symbols only, names only, or both symbols and names. Furthermore, a series of control words allow the user to request hints, find out the answer, and override any of his own previous or the computer's current decisions as to the direction the drill should take. All these features of ELEMENTS make it a good example of the CAIR principles applied to a drill program.

## TUTORIAL PROGRAMS

Tutorial programs are those in which the user response is much more complex than for drill programs (i.e. the user is asked to solve a problem in stoichiometry), and the computer is equipped not only to monitor the user's responses, but also to analyze them, and, if necessary, to tutor the student in a methodical, step-wise fashion. Tutorial programs may be linear or nonlinear. In the former case the program has a fixed starting point and its various sections are executed in a fixed order. Nonlinear programs have a more flexible structure, entry being permitted at any point, with skipping and/or backtracking at the discretion of the user and/or computer. Among the tutorial programs we have written, pH AND LOGS and our INSTRUMENTATION PACKAGE have received the most use (2,3,4).

pH AND LOGS is a nonlinear tutorial program consisting of 18 sections ranging in subject matter from exponents to pH problems. The user may start at the point at which he feels best qualified, with the option of moving back to a previous section or ahead to a more advanced one either on his own volition, or on the advice of the computer when such is forthcoming. Since this program deals with numerical problems, its resource of problems is essentially infinite; each use will emphasize the same principles, but the randomly generated problems will always be different. Users can request detailed solutions to the problems, with explanations given at every step, and with the advantage of immediately thereafter attempting a similar problem on their own, under the watchful eye of the computer.

The INSTRUMENTATION PACKAGE consists of three linear tutorial programs in SPECTROSCOPY, GAS CHROMATOGRAPHY, and ELECTRONICS designed for use in our upper level chemical instrumentation course. The nature of the material in the programs is such that user responses are required to be in words, phrases, or sentences; hence, a multiple choice format was chosen to simplify handling of user responses. Wrong answers result in the presentation of brief expositions on the subject matter, after which the user is invited to reanswer. Self-pacing is achieved by preventing movement from one section of the program to the next unless understanding of the material is demonstrated by a satisfactory right to wrong answer ratio. Each student must finish the programs as a requirement of the course, but how fast a program is finished is irrelevant. These programs have proven to be very popular with the students, whose main criticism has been that more of them are not available for other areas of the course. Comments entered into the computer by students taking the course the Spring, 1973 semester include:

> "...(the program) has helped me more than any other (teaching device)...I have met thus far..."
>
> "It has helped me realize what I thought I knew but didn't."
>
> "Computer programs for this course is an excellent idea and of valuable assistance in learning the course material. I would like to see...programs in other courses."

Other student comments concerned specific items in the program. We have never had a comment, either via the computer or directly to an instructor, that conveyed a negative attitude towards the use of CAI after the student had had some experience with the programs. Significantly, most resistance to the use of CAI comes from instructors, not students.

## A CAI-INTEGRATED LABORATORY

There are three general approaches to the use of the computer as an educational tool in association with laboratory courses. These are in calculations, simulations, and computer-integrated laboratory experiences.

Probably the simplest way for a chemistry instructor to "get into CAI" is to use the computer as an aid in checking calculations (or directly performing them) and for class records of unknowns, grades, etc. Typical of this approach is an APL program designed by Dehner and Norcross (5), supported on their system's IBM 360 computer to check students' raw data for reasonableness, and later to check the students' calculations for accuracy. Since there is a minimal amount of feedback inherent in this system when an error is detected, this type of bookkeeping approach could as well be done with a programmable desk calculator.

Simulations, on the other hand, offer great potential for CAI use in that they save time, money, and offer unique opportunities for individual students to get off the beaten track. Laboratory simulations have been described by Lagowski (6) and others. In a titration simulation we have written, the student is assigned an "unknown" base which he titrates against an "acid" whose concentration he specifies. He may use all or a portion of the unknown and may make dilutions if he wishes. All physical parameters normally associated with titrations must be fixed by the student, and can be varied whenever necessary. The course of the titration is followed with a simulated pH meter. Data may be plotted in a number of ways specified by the student, and the computer may be used in a desk calculator mode for manual calculations.

Such simulations are a facile means for exploring what happens when the concentrations of acid and base are very different, or what information can be obtained from various plots (such as hydrogen ion concentration vs. pH, or first derivative plot of pH vs. ml titrant). They are not, of course, a substitute for actual experience with laboratory equipment; on the contrary, they may in some cases presuppose such experience. Simulations have also been criticized on the grounds that they either produce "ideal" data, or that "errors," when introduced as random deviations from theoretical results, are applied arbitrarily without accounting for variations in technique from one student to the next.

In conjunction with our course for nonscience majors, we have developed a laboratory experience which employs the third type of use of the computer in the laboratory, an integrated laboratory experience and self-paced CAI approach which uses the computer in tutorial and simulation modes in a program which expands the work done with real equipment in the laboratory.

The laboratory experience involves finding the volume of a glass bulb by taking a series of pressure-volume measurements on the air in the bulb, then using Boyle's Law to calculate the volume of the gas at room temperature and atmospheric pressure at the time of the measurements. Enough data is taken for four volume determinations. The calculations may be done by hand, or via the computer program.

The computer program first ascertains that the student understands how to calculate the volume of the bulb from his data. If he does not, the computer is capable of going through a detailed demonstration of how this is done via a series of leading questions which require constant interaction of the student with the computer, assuring that the student will eventually be able to do the calculations on his own.

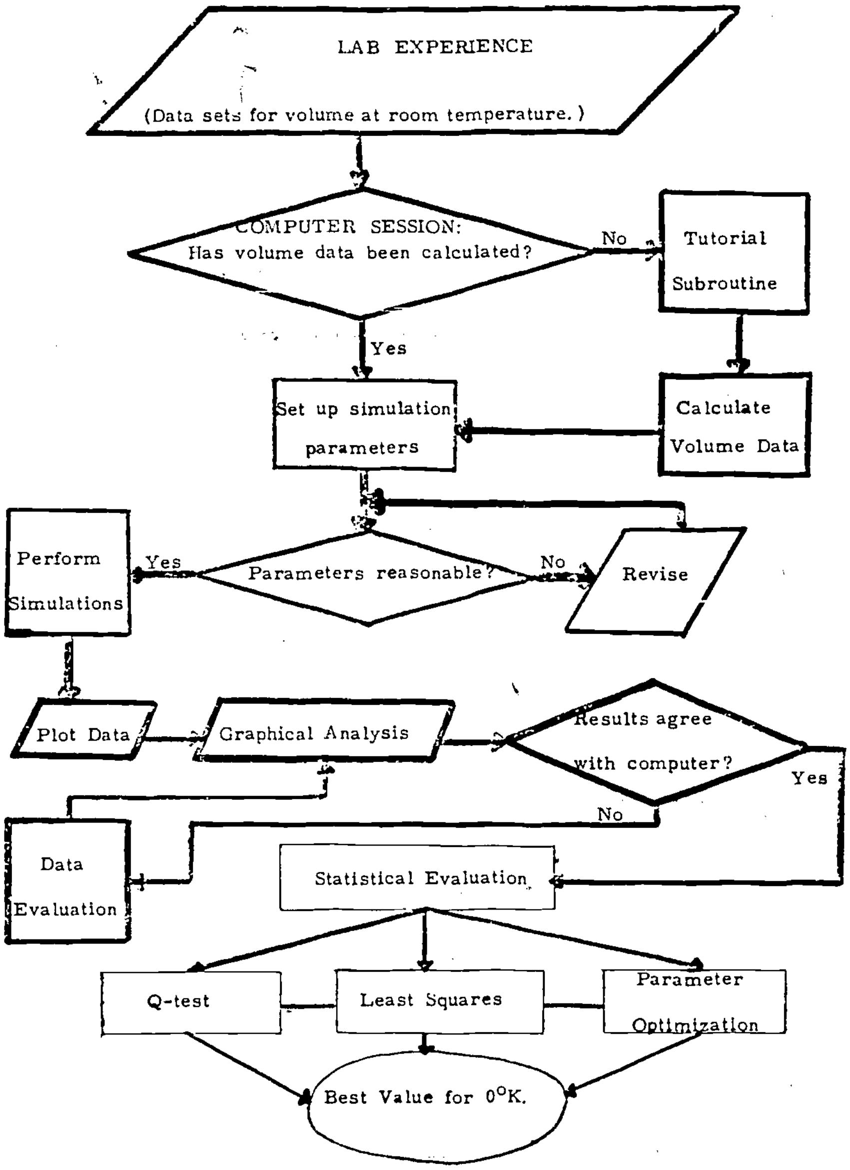
The computer program extends the Boyle's Law experiment by simulating a new experiment in which volume-temperature data is taken on a gas, the purpose of which is to find the value of absolute zero by extrapolating a volume/temperature plot to zero volume. The student must set all relevant physical variables in the experiment, including choosing an appropriate gas for the simulation. All of his decisions will affect his results to some degree, as he can himself discover by simply repeating the experiment while varying some parameter. Such repetitions are much more easily accomplished with a computer simulation than would be possible with actual laboratory equipment. The results of the simulation are also affected by the real-life laboratory data the student took, because the program employs a determinate error related variance (DERV) system to generate random errors in the simulated data. This is done by calculating the variance in the real-life data, and generating errors with this variance to bias the simulated data. DERV assures that the careful worker will not be penalized by an arbitrary "average" error in his simulated data, while at the same time, the sloppy student does not escape the consequences of his technique on the computer.

After the student has determined the value of absolute zero by extrapolation of the plot obtainable from the computer, he has a number of options he can choose from to improve his results (if he wants to), including statistical analyses of his original data, and optimization of simulation parameters where necessary, such as using helium as the gas for the simulation instead of, for example, air or carbon dioxide.

Figure 1 shows a general outline of the entire CAI laboratory experience.

We feel this type of integrated laboratory-computer approach is an example of a most fruitful application of computers to the teaching laboratory. The student is provided help with principles in the tutorial mode, but he is essentially on his own in the simulation mode, observing immediately the consequences of his decisions (rather than being told a decision was "right" or "wrong"), and with the capability of improving his decisions, and learning therefrom, to the extent his interest allows.

Figure 1


LAB EXPERIENCE
(Data sets for volume at room temperature.)
COMPUTER SESSION:
Has volume data been calculated?
No
Tutorial
Subroutine
Yes
Set up simulation
parameters
Calculate
Volume Data
Perform
Simulations
Yes
Parameters reasonable?
No
Revise
Plot Data
Graphical Analysis
Results agree
with computer?
Yes
No
Data
Evaluation
Statistical Evaluation
Q-test
Least Squares
Parameter
Optimization
Best Value for $0^{o}$K.

## References

The interested reader will find detailed descriptions of our drill and tutorial programs mentioned in this paper in the first four references. A complete description of the integrated computer gas law laboratory will appear later this year in the *Journal of Chemical Education*. Additional information may be obtained by writing the authors.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# PROBLEMS IN STARTING A CAI SYSTEM

by

Ronald Crain* and Alfred Lata*

The term, "CAI System", usually invokes pictures of a computer which has been dedicated to teaching with a language that is tailored to make CAI programming easier for the author. If you have funds to either purchase a complete CAI system like the one developed at the University of Illinois, or you can afford to access such a system via phone line then the comments made in this paper will be of little value. However, if you wish to utilize your present computer or acquire a time sharing system for CAI we hope that this paper will give you some help.

Unfortunately, there are no easy paths to start a CAI program even when you have the support of your peers. The problems can be divided into essentially four categories: (1) Inhibitions to even getting approval to start; (2) What language for programming should be used?; (3) What kinds of programs can best be utilized for CAI? (4) Where can one access programs that have already been developed?

Dr. Ron Collins, our next speaker, will be discussing some of the inhibiting factors for CAI development such as a lack of reward system so we do not wish to dwell on this aspect of the business even though it is important. Other sources for such information can be found in a report to the National Science Foundation by Anastasio and Morgan and also in an article by A. R. Molnar (Table 3). Instead, we will discuss the one overriding concern which has been constantly raised by teachers and administrators.

The major obstacles in even interesting your colleagues or administration in thinking about using a computer for teaching are usually obscured by one large argument: COST EFFECTIVENESS. It is our opinion that this term hides the many inhibitions on the use of the computer for teaching in an academic program. Briefly, some of these are ignorance, fear of the computer and its sociological implications, a shifting of financial support from pet projects, etc. Therefore, before giving any information on the development of a CAI program we wish to discuss the money problem.

This term, 'cost effectiveness', is a real consideration and we do not mean to denigrate its importance. Our point is that it is used spuriously as an irrefutable argument against CAI when the facts do not support cost effectiveness as a standard criterion of decisions in chemistry, and most likely in higher education.

We would like to apply this cost effectivenesss approach to some standard equipment which most chemists apparently agree are very important in the

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education of students. These are classified as spectrophotometers (NMR, mass, infrared, etc.) but the list could be expanded to include almost any large investment in hardware.

We shall first examine the educational effectiveness of expensive equipment in teaching students chemistry. Ask yourself some very simple questions: Can I teach infrared and NMR spectral interpretation without letting the students have access to the equipment? Or better yet, do your students actually operate your spectrophotometers? After all, learning to to use a piece of equipment is training and not education. The equipment is nice, but is it really educationally effective? Please note that we are not arguing that one should do away with all such equipment. We merely wish to place it under the eye of 'cost effectiveness'.

The second half of the problem deals with the cost. Let's apply the cost arguments to justify the purchase of the least expensive piece of equipment, infrared spectrophotometers. A figure that is often quoted as being reasonable is 50 cents a spectrum (this includes the initial investment, repairs, operating personnel, etc.). That figures out at about $2/hour and if one is generous we could say that it is less. The cost for a mass or NMR spectrometer would be considerably higher. Can you really argue that these instruments are cost effective in your teaching program?

The cost of a CAI system can be treated in the same manner. Figures for the cost per hour range from 40 cents and up. My personal opinion is that $1/hour is currently attainable. This compares quite favorably with infrared and is much cheaper than mass or NMR.

If one really wishes, and insists, that education truly be cost effective then we academicians are in trouble. The accrediting agencies consider 16 hours a semester a full teaching load. At the major universities a simple cost effective measure can be worked out by insisting that all faculty teach 6 hours a semester and the remaining 10 hours can be distributed among the graduate school duties, research, publishing, etc. The savings would amount into the millions when about half of the staff is dropped. It would be difficult to increase the teaching load in the small non-research oriented institution; in their case one could insist that there be only one lecture section for each course offered and that courses with low enrollments be dropped or taught every other year. These are extremely good cost effective measures and some educational systems are actually looking at them very carefully. Cost effective advocates should be wary that they don't stumble over their own prejudices.

However, we all know that there are very good arguments for maintaining small class sizes, a strong research program, a CAI system, or maintain large library holdings. These all speak of the quality of education and seldom deal with the arguments of cost effectiveness. The expensive modern laboratory equipment costs may improve the quality and increase the effectivness (questionable) of education but is the expenditure really worth it? If the answer to this question is yes, then on the same basis one is in an equally excellent position to justify the adoption of CAI in the teaching program.

Therefore, the primary question is one of priorities rather than cost effectiveness. Since the same criteria have not been logically applied to all areas of higher education, your major problem will be to try to make your colleagues and staff members into honest people. If they openly admit that research, buildings, or something other than educating undergraduates is the main priority for determining the expenditure of funds it will be pointless for you to gather data on the cost effectiveness of CAI as a tool and adjunct to your teaching program. It is simply placed on the low end of priorities and allowed to die. On the other hand, if there is a refusal to recognize the priority basis for decision making on money matters you would be far wiser to first expend your energy on getting the priority system currently in vogue stated publically. That could be embarrassing for many institutions.

We shall now assume that you have at least overcome these obstacles and have received tacit approval to initiate programs for use on a time sharing system. The personal experience of the authors and many others is that the amount of time and energy needed to write CAI programs is not small. And, you will want to start as soon as possible by acquiring work done by others and hopefully slowly build your own library of programs.

The problem of mounting another person's program on your system is not a simple job unless you are both using the same computer system. This brings us to the discussion of programming langauges. It is possible to use almost any language for a CAI program. Some are better than others and may have special features that are nice for certain routine functions. If you are not locked in on a particular language for CAI then we recommend that FORTRAN IV and/or BASIC be adopted. These two languages offer the maximum ease of transferability of programs. You can acquire developed programs and others can utilize your work. Most other higher languages require a reworking of the entire program and it is almost easier to ignore the original work and build your own algorithm. Better documentation of all programs would make this task easier.

Table 1 contains a limited list of people who can be contacted for the purpose of acquiring programs. Many of these are not very well documented, some are still filled with errors, and some of the pedagogy presented is questionable. Both Dr. Collins and Dr. Denk have collected programs from all over the country and have compiled a brief description of them. Actual printouts, punched decks, or tapes can be obtained from the original authors. If you should request listings please be patient and be prepared to pay for the cost. Their time and money are limited. Dr. Lower, of Simon Fraser University, has informed me that he has 30 pounds of printout on programs written in APL. Therefore, one should first request a description of the programs before asking for the actual printouts on all available programs.

One other source will soon be available through the efforts of the chemistry committee of CONDUIT (sponsored by NSF). Programs are being screened for use on five network systems and a brief description of each is being compiled. These programs are considered by the committee and the users as having sound pedagogy and will run without serious errors. The

Table 1

Listings of available programs
(not complete, but a good
starting point)

Dr. Ron Collins, Director
Eastern Michigan University Center for the
Exchange of Chemistry Computer Programs (EMU-CECCP)
Eastern Michigan University
Ypsilanti, Michigan 48197

Dr. Joe Denk
Curriculum Development Manager
North Carolina Educational Computing Service
Box 12175
Research Triangle Park, North Carolina 27709

Dr. Karl L. Zinn, Director
Project CLUE
13135 Hill Street
Ann Arbor, Michigan 48104

Dr. Kenneth R. Jacobs
Oberlin College
Oberlin, Ohio 44074

Dr. Luke Krebs
Manager of Special Projects
Computing Center
Washington State University
Pullman, Washington 99163

Department of Chemistry
Beloit College
Beloit, Wisconsin 53511

Authors
University of Kansas
Lawrence, Kansas 66044

For APL Users contact:
Dr. S. K. Lower
Department of Chemistry
Simon Fraser University
Burnaby 2, B. C. Canada

listings should be available by September and inquiries can be sent to either Dr. Collins (chairman) or to me.

The literature available on CAI programs is actually not very large and it is scattered and somewhat difficult to obtain. Many programs are not even listed in literature sources (another problem). Table 2 gives a few pertinent references which contain chemistry CAI programs. Again, this is not meant to be a complete listing. They are merely the key journals and proceedings of meetings which we felt that one should consult for specific CAI programs. Table 3 contains some general literature which should help introduce you to the experience of other workers in the area on the use of computers for teaching.

Many of the types of programs that are currently available are usually not designed for time sharing use. Rather, they have been developed for the batchworld of punched cards and normally utilize the computer's ability to crunch numbers. Programs involving alphanumeric symbolic manipulation are just now beginning to emerge in FORTRAN. These types of programs clearly show that we have only begun to scratch the surface on using the computer to capture the non-numeric logic of chemistry. The most obvious example in chemistry is the manipulation of organic structures.

Table 2

Literature Listings of Programs
(not exhaustive)

Conference on Computers in Undergraduate Curricula, 1970
Dr. Gerard P. Weeg, Director
Computer Center
University of Iowa
Iowa City, Iowa

Conference on Computers in the Undergraduate Curricula, 1971
Dr. Thomas E. Kurtz
Dartmouth College
Hanover, New Hampshire

Proceedings of the 1972 Conference on Computers in Undergraduate Curricula
Southern Regional Education Board
Atlanta, Georgia 30313

Conference on Computers in Chemical Education and Research
D. F. M. Miller
Northern Illinois University
De Kalb, Illinois

Journal of Chemical Education

Chemical Abstracts (See COMPUTERS and COMPUTER PROGRAMS)

Table 3

Some General Literature on Computers in CAI
which might be helpful

Computers in Instruction: Their Future for Higher Education, Roger Levine (Editor), Rand Corporation

An Evaluative Review of Uses of Computers for Instruction, Karl L. Zinn, Project EXTEND, University of Michigan, 109 East Madison St., 48108

Factors Inhibiting the Use of Computers in Instruction, Ernest S. Anastasio and Judith Morgan, EDUCOM Interuniversity Council, Inc., 1972

Computing in Higher Education 1971: Successes and Prospects, EDUCOM Interuniversity Communications Council, Inc.

Modern Teaching Aids for College Chemistry (18), Advisory Council on College Chemistry, Stanford University, Stanford, California

Critical Issues in Computer-Based Learning, Andrew R. Molar, Educational Technology, August, 60-64 (1971)

The interactive CAI programs can be viewed as belonging to simple drill, tutorial, data retrieval, simulation and 'free style'. The obvious use of the computer in calculations will be ignored and examples for these alphanumeric CAI programs will be cited.

The simplest type of programming is the frill form. For example, I have a program which randomly generates an inorganic formula and the student types in the name (or it generates a name and the student enters the formula). If there are two wrong answers the correct one is given and the student is given another one from among about 400 possible ones. These programs are not hard to write and they serve a good purpose for those students who require drill of this type. But, if this is as far as you go in your CAI then you have definitely not maximized the capabilities of the computer.

The above program could be transformed into a tutorial type by rearranging the sequence so that the student is given diagnostics and the next question is determined from previous answers. Mr. Lata has written some excellent programs on balancing redox equations using this tutorial approach. Again, if one stops here in CAI programming the beauty of CAI will not be fully realized.

We have told students that chemistry is more than mathematics. There is a large area of chemical logic that has been developed. Often we flail the air with our arms when we use it and we ask students to show that they know more than the memorized facts on examinations. If we have a developed logic, then the computer can be given that logic. Now the student has more than just an instructor to talk to on chemical systems. The computer is programmed with this logic captured. In addition, the computer is available and very patient. No judgements, or anger, or frustrations are shown if the student should make the same mistakes over and over.

One of the programs developed at Kansas has incorporated the logic used for aromatic substitution reaction. There are over 25,000 compounds available for manipulation by the student. The student selects a starting compound and adds the reagents. The computer decides what the resulting compound will be using the same chemical decisions made by an organic chemist and prints out the resulting structure. Diagnotics are included for errors or reactions that are not allowable. This program has been run on small computers with only 8K of core available.

Another type of program which can utilize all of the above styles of programming, including data retrieval, would be laboratory simulation programs. For example, qualitative organic analysis or inorganic qualitative analysis. Both types are available at Kansas in FORTRAN IV and Mr. Lata is giving a paper on one written in BASIC.

We would like to conclude this paper with a brief discussion on some recommendations which would improve the availability of programs and their transferability to other systems.

We have already mentioned our recommendation on adopting FORTRAN and/or BASIC as a standard CAI language(s). In addition we would like to add that certain changes be made in FORTRAN and adopted nationally to make the writing and transferring of programs easier. There is a need for the capability of string manipulation standards and file manipulation capabilities (e.g., as found in COBOL) so that many data files can be stored on disk or tape and accessing them is not difficult.

The problem of transferring a program to another system is not trivial when the same language is being used. Documentation standards must be adopted so that the algorithms developed can be more easily transmitted to other users. Here again, one is stymied because the writing of a good program requires a large commitment of time and documentation asks that additional effort and time be spent on it for other people. If there is no reward system one is not inclined to worry about devoting more time on the project.

How can we help reward faculty for CAI work? The best method would be to have it come from the university system. Practically, it would help if there was a good way to allow publishing of the work since counting publications is already a part of the reward system. The literature contains many references to CAI programs where the work is presented as a magic box. The results are given but no where does it help you to duplicate the results. This would be similar to reading about a new synthesis without being given an experimental procedure or any of the reagents used. There is very little discussion on what pedagogical problems were solved or how the program was designed.

We do not suggest, or recommend, that journals print out the actual programming statements. If you desire that kind of information write the author for a printout of the program. What we are suggesting is that the programming strategy be given. That way, if the author use COURSEWRITER and you have BASIC, there is a good chance that a programmer can simply devise a similar one written in BASIC.

This suggestion will require that either editors send manuscripts on CAI programs to those who are knowledgeable in what is going on in CAI, or learn how to distinguish between what is old, what is trivial, and what is helpful to others in reproducing their results.

THE ROLE OF COMPUTERS IN CHEMICAL EDUCATION:

A NEW ACS COMMITTEE

by

Ronald W. Collins*

The Division of Chemical Education of the American Chemical Society has organized a new committee to evaluate the present and future role of computers in chemical education. This committee consists of fifteen members who represent both large publicly-supported universities and small private colleges. The members display outstanding expertise in all areas of computing, including CAI, graphics, the use of computer-generated exams, and computer-instrument interfacing. Their collective hardware experience includes large machines, minicomputers, and hybrid analog-digital computers. The complete list of committee members is given below. The committee is currently preparing a concise report which will summarize the present status of instructional computer usage in chemistry. It is hoped that this report will both serve as a source of pertinent technical information for ACS members, and as the basis for the development of guidelines governing future ACS-sponsored activities related to the educational use of computers. Under consideration as techniques for information dissemination are the use of audio tapes and videotapes, as well as live short courses and/or workshops which could be held in conjunction with regional or national ACS meetings. Also, the feasibility and desirability of ACS involvement in the publication and/or exchange of computer programs and computer-oriented educational materials is being studied. Furthermore, in addition to focusing directly on the problem of the dissemination of information on currently-available computer-based educational materials, the committee is also studying methods for improving faculty competency in the areas of specialized computer hardware (e.g., hybrid digital-analog computers) and computer-instrument interfacing. In these cases the primary emphasis is not on the use of the computer as a vehicle for chemical education, but rather on insuring that chemistry instructors are adequately prepared to educate students on the numerous diverse roles of the computer within the field of chemistry.

The committee is relying primarily on its own members for input information to be included in its report; however, suggestions and comments from interested chemical educators are welcomed. To facilitate suggestions and the expression of opinions, a questionnaire has been included with this copy of the Symposium Proceedings. Please return your copy to the committee chairman at the address listed on the form.

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## Committee Members

| | |
|---|---|
| Ronald W. Collins, Chairman | Eastern Michigan University |
| Joyce H. Corrington | Xavier University (La.) |
| Ralph M. Deal | Kalamazoo College (Mich.) |
| Thomas R. Dehner | SUNY - Binghamton |
| Clare T. Furse | Mercer University (Ga.) |
| Frederick M. Hornack | Univ. of North Carolina - Wilmington |
| K. Jeffrey Johnson | University of Pittsburgh |
| Charles E. Klopfenstein | University of Oregon |
| Joseph J. Lagowski | University of Texas |
| John W. Moore | Eastern Michigan University |
| Sam P. Perone | Purdue University |
| Stanley G. Smith | University of Illinois |
| Brock Spencer | Beloit College (Wis.) |
| Fred D. Tabbutt | Evergreen State College (Wash.) |
| Roy Upham | Saint Anselm's College (N.H.) |
| W. Todd Wipke | Princeton University |

COMPUTER-BASED TEACHING OF CHEMISTRY

by

Stanley G. Smith* and James Ghesquiere*

Some computer-based teaching programs designed to facilitate learning will be illustrated on the PLATO IV computer-based teaching system. Although a wide variety of types of programs have been developed, lesson material oriented toward an introduction to the theory and experimental details of subsequent laboratory work will be demonstrated. These programs are designed to assure that the student has a basic understanding of both the objective of an experiment and details of the actual laboratory work by means of a computer generated simulation which provides each student with the essentially instantaneous assistance of the instructor. The simulations also include collections of experimental data and its analysis with on line tutorial help when needed. Specific examples of this approach, illustrated directly on a PLATO IV terminal connected to the computer, at the University of Illinois computer-based teaching laboratory via standard telephone lines, includes acid-base titration, Figure 1, purification by crystallization and qualitative

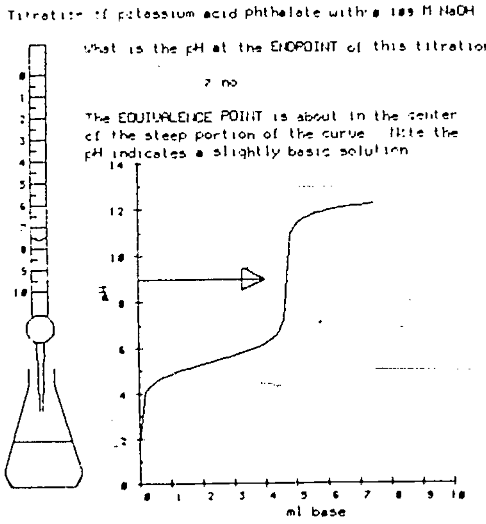


Figure 1. One display in PLATO IV lesson on titration.

analysis. Additional programs demonstrated at the terminal include interpretation of IR spectra which are projected directly on to the plasma panel from a color microfiche, nmr, and organic synthesis.

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Use of computer generated summaries of data collected during class room use of these programs facilitates subsequent refinement of the teaching techniques employed as well as making it possible to rapidly identify students who need the individual attention of the instructor. The wide diversity of learning rates of individuals in a typical class is illustrated by computer generated graphs, Figure 2, and statistical analysis of errors, help, time, and, where appropriate, sequence of procedures used by each student in solving specific problems. The use of such data facilitates the systematic improvement of the pedagogy employed in the lesson material in order to optimize the learning rate.

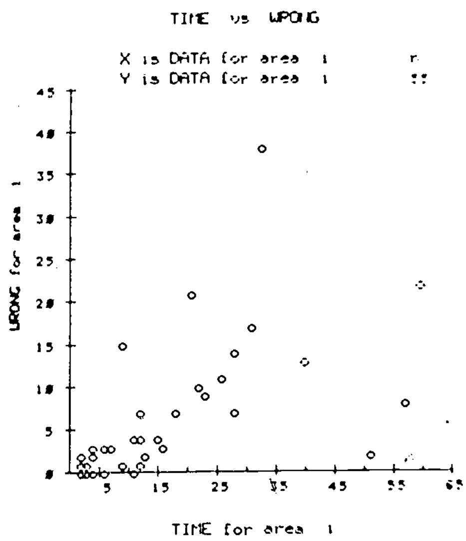


Figure 2. Plot of time _vs_ errors for a class of 55 students working a segment of a lesson on titration.

THE USE OF THE PLATO COMPUTER-BASED EDUCATION SYSTEM

FOR SELF-PACED INSTRUCTION IN GENERAL CHEMISTRY

by

Robert C. Grandey*

The general chemistry program for transfer students at Parkland College, a two-year community college, consists of laboratory work, group discussions and the use of the PLATO computer-based education system.

In order to schedule efficiently the group discussions and the laboratory work, which often involves group projects, we require that the class maintain a rigid weekly schedule of topics. Although we do not provide for an individual to work independently of the class, within each week's assignment we do provide for individualized and self-paced instruction by using the computer. Each week, the students are assigned lessons to be completed at the computer terminal. This year, while we are developing the lessons, the use of the computer is optional, but in the Fall, the number of lecture-discussions will be decreased, and everyone will be required to use the computer. The amount of computer material, as compared to the lecture-discussion material, varies from week to week depending on the type of material. Problem solving topics, where the wide range of student abilities becomes most obvious, require more computer material.

The computer-assisted lessons present and evaluate one or more concepts. Each concept is introduced by some explanation, simulation, or examples, and each concept is evaluated according to specific criteria. In some cases, the application of several concepts to a given situation is also evaluated.

The pace of the material is controlled by the student in three ways: he works at his own terminal at his own rate; he is often given choices of the material to see; and an evaluation of his performance may speed him up or slow him down.

The computer is used to illustrate concepts which are difficult to illustrate in the normal classroom because they require motion, long or very short time, or are so complex that the number of parameters is very large. The kinetic molecular theory, dynamic equilibrium, ligand field theory and inorganic qualitative analysis are a few examples. In these simulations, the student can control the parameters and can spend as much time as he wants investigating the phenomena.

Usually there are several correct procedures or sequences which the student may follow. In the lesson on qualitative analysis, the student is required to separate a known solution of four cations (1). The computer shows

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him the results of the addition of any of five reagents, taking into account the pH and the prior addition of reagents. When the student feels that he has the ions separated, the computer checks his results. In this lesson, the student is in direct control of the time he spends and of his specific activities. He decides when he thinks the ions are separated; he decides what reagent to add next; he may even deicde to start over, get a new mixture, or investigate one ion at a time.

The computer is also used for lessons which require the student to solve a number of problems, particularly multiple-step problems such as calculating the molarity of a solution. The computer is "taught" to diagnose the student's performance and to provide instruction which is tailored to the needs of the student.

The primary goal of individualized instruction is to take a student at the fastest possible rate into new material and guarantee his comprehension. Students should not only be allowed to go at their own pace; poor students should get meaningful assistance, and good students should not be forced to do problems which are too easy for them. This goal implies that the student's performance must be evaluated throughout the lesson.

## Lesson Design

The first step in designing a lesson is to determine the concepts and the order, if order is important, in which they will be presented. The introduction for each concept depends on the type of concept. For example, the relationship between the number of protons and the atomic number is introduced by showing, for a few elements, a chart of the atomic symbol, atomic number, mass number, number of protons and number of neutrons. The student can then figure out the relationship without being directly told. Other concepts, where size changes or motion are important, are introduced by animations. The introduction is kept relatively brief, at least for the first presentation.

After the introductions have been determined, minimum standards are set for evidence of mastery of each concept. If the concept involves distinguishing a pattern which can be generalized, such as the relationship between the atomic number and the number of protons, evidence of mastery of the task often is the successful completion of n items, j in a row. If the concept involves putting several ideas together, such as solving a multistep problem, the successful solution of one or more complicated problems may be the minimum requirement.

To make the lesson efficient, the introduction is kept brief and the criteria questions are rather difficult. This assures that the good students do not get held back. If the entire lesson is new material and there is a definite sequence, the students start with the first introduction. If, however, there is no defined sequence, the students are able to choose the order of study. If the lesson is used as a review, the student is given the choice of the areas for review or he is given the criteria questions. When determining a student's entering level in a lesson in which there is a definite sequence, the most difficult concept should be tested first. If the student answers correctly, there is no need for review. If the student cannot pass the most difficult criteria, he is tested at approximately the midpoint in the lesson. If he passes these criteria, he is tested on the next highest concept; if he fails, he is tested on the next lowest concept until his level is determined.

After the brief introduction and rather difficult criteria questions are programmed and the lesson has been checked by another chemistry instructor, one or two students are asked to work through the lesson. Places that seem too easy, too difficult or confusing are noted. The material is then revised by shortening areas that are too easy and expanding slightly the most difficult areas.

At this point, the lesson is ready for the good students, but assistance has not been provided for those who get into trouble. Deciding when a student is in trouble is the first problem. Allowing the student to decide when he needs help is usually effective; however, a careful record of the student's performance provides the evidence for providing assistance for those students who do not realize or are afraid to admit that they need help. In general, the student is required to answer correctly each question in the lesson. Several trials at the same question are evidence of trouble. It is important that the student is challenged without being frustrated.

The type of assistance depends on the nature of the problem. Since the initial structure of the lesson is written with brief introduction and rather difficult questions, providing more detailed instructions or taking problems in smaller steps often helps. Another form of assistance that has been proven useful is to diagnose what is wrong with the student's answer. Students would rather know what was wrong with their answers than know what the right answer was (2).

In order to provide these forms of assistance, general routines must be written. For example, to calculate the molarity of a y liter solution of x grams of A, a very standard procedure is followed. The computer can be programmed ("taught") this procedure. It can then be trained to ask the student questions about his specific problem.

Similarly, the computer can be taught to determine if a chemical equation is balanced. It can find the student's errors and tell him about them. The computer can be taught that an equation must be balanced by both charge and mass and that the order of reactants and products is not important. It can be taught how to count atoms, i.e., look at coefficients, subscripts, subscripts after parenthesis and brackets, improper superscripts and improper characters (typing errors).

Special routines have also been written to solve and analyze answers to stoichiometry problems and elemental composition problems. These routines permit the students and instructors to supply their own problems and receive assistance. This adaptability is particularly important because the same lessons are used with different problems by different instructors.

When lessons are written in this way, the amount of time a student spends on a given lesson depends on how fast he proceeds, what he chooses to do, and how well he does. Instruction presented in this manner is truly self-paced.

## References


(1) Francis, Larry D., "Computer-Simulated Qualitative Inorganic Chemistry", J. Chem. Ed. (in press).

(2) Ausubel, D. P., and Robinson, F. G.,"School Learning",Holt, Rinehart and Winston, Inc., New York, N. Y., 1969.

SELF-PACED INSTRUCTIONAL PROGRAMS

In addition to the programs described in this Symposium, several other self-paced activities have been brought to the Chairman's attention:

1. "Three-Column Instruction Form", H. H. Bliss, Department of Chemistry, University of Oklahoma, Norman, Oklahoma 73069.

2. "Self-Paced Instruction", Jesse H. Day, Department of Chemistry, Ohio University, Athens, Ohio 45701.

3. "A Self-Paced Approach to Biochemistry", Richard Doyle, Department of Chemistry, Denison University, Granville, Ohio 43023.

4. "Introduction to Chemistry Using the Keller Approach", Lucy Edelbeck, Department of Chemistry, Dominican College, Racine, Wisconsin 53402.

5. "Self-Paced Learning vs. Programs of Instruction", G. P. Haight, Jr., Department of Chemistry, University of Illinois, Urbana, Illinois 61801.

6. "Learning Oriented Chemistry Instruction: An Audio-Visual Approach", Charles Howard, Department of Chemistry, San Antonio College, San Antonio, Texas 78212.

7. "Self-Paced Physical Chemistry", Marwin Kemp, Department of Chemistry, The University of Tulsa, Tulsa, Oklahoma 74104.

8. "Modular Instruction", Tom Kenney, Department of Chemistry, Montgomery Junior College, Rockville, Maryland 20850.

9. "Chemistry Teaching by the Keller Plane", Micah Wei-Ming Leo, Department of Chemistry, Barrington College, Barrington, Rhode Island 02806.

10. "Self-Paced Learning in a First Year Course", David K. Lewis, Department of Chemistry, Colgate University, Hamilton, New York 13346.

11. "Computer-Augmented Lectures", F. A. Matsen, Department of Chemistry, University of Texas, Austin, Texas 78712.

12. "Self-Instructional Units in Chemistry", B. Paige, Department of Chemistry, Antelope Valley College, Lancaster, California 93534.

13. "The Systems Approach in a Basic Chemistry Course", Dexter S. Plumlee, Jr., Department of Chemistry, Northern Virginia Community College, Annandale, Virginia 22003.

14. "Mastery of Performance Objectives as a Basis for Written Evaluations", Miriam M. Stimson, Department of Chemistry, Kenka College, Kenka Park, New York 14478.

15. "Individualized Instruction in Chemistry", Samuel von Winbush, Department of Chemistry, State University of New York College at Old Westburg, Long Island, New York 11568.

16. "Organic Chemistry via the Keller Plan", Charles D. Warner, Department of Chemistry, Missouri Valley College, Marshall, Missouri 65340.

17. "Experience with the Keller PSI Method in First Year and Upper Division Chemistry", J. M. White, Department of Chemistry, University of Texas, Austin, Texas 78712.